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A bioarchaeological analysis of the effects of the Xiongnu empire on the physical health of nomadic groups in Iron Age Mongolia

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A BIOARCHAEOLOGICAL ANALYSIS OF THE EFFECTS OF THE XIONGNU EMPIRE ON THE PHYSICAL HEALTH OF NOMADIC GROUPS IN IRON AGE MONGOLIA

by

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ABSTRACT

The Xiongnu Empire (c. 200 BC – AD 100) was the first instance of imperial level organization by nomadic groups of the Mongolian steppe. Over a century of historical and archaeological research has produced a large body of scholarship on the political, military, and sociocultural structures of Xiongnu society. This study adds to the growing body of recent bioarchaeological research by using multiple lines of evidence to address the impacts of empire formation on the physical health of those who lived under the influence of Xiongnu rule.

Models of Xiongnu empire formation posit stable access to Chinese agricultural goods and reduction in violent conflict as major motivating factors in establishing imperial-level organization among Mongolian nomadic groups. By gathering data from the skeletal remains of 349 individuals from 27 archaeological sites and analyzing the

frequency of ten dietary and health indicators, this study addresses these claims. The Xiongnu imperial expansion and administration resulted in the movement and/or displacement of nomadic groups, consequences that are documented in Chinese historical texts, but its impact on population structure is poorly understood. Craniometric data collected from this skeletal sample were used to conduct a model-bound biological distance analysis and fit to an unbiased relationship matrix to determine the amount of intra- and inter-group variation, and estimate the biological distance between different geographic and temporal groups.

This skeletal sample includes individuals from 19 Xiongnu-period sites located across the region under Xiongnu imperial control. Individuals from eight Bronze Age sites in Mongolia were included to establish pre-Xiongnu health status. One agricultural site within the Han Empire, contemporaneous with the Xiongnu, was included for comparison.

The results of this study indicate that Xiongnu motivations for creating a nomadic empire were considerably more complex than current models suggest. Although historical texts document that the Xiongnu received agricultural products as tribute from China, dietary markers indicate the Xiongnu diet was more similar to that of their Bronze Age predecessors than to their agricultural Han neighbors. The movement of people across the Mongolian steppe during the Xiongnu period created a more phenotypically homogeneous population structure than that of previous Bronze Age groups.

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Chapter 1: Introduction

1.1. Introduction

The Xiongnu (匈奴) Empire was a supra-tribal confederacy that emerged on the Inner Asian steppe in the 2nd century BC and unified ethnically and culturally diverse tribal groups across the steppe under the control of the elite Xiongnu lineage, and maintained political control of the region until its disintegration in the 2nd century AD. The Xiongnu Empire is the first appearance of a steppe-wide political alliance of nomadic tribes across the Mongolian steppe, which incorporated the modern country of Mongolia and the Chinese province of Inner Mongolia, as well as surrounding areas.

The grasslands of the Mongolian steppe are not well suited to the cultivation of crops. The continental climate of Mongolia has a short growing season, extreme temperatures, and too little rainfall to support intensive agricultural production. The main subsistence strategy in this region has been nomadic pastoralism, which takes advantage of the vast amount of land available for use as pasture. The environment and mode of economic production has played a significant role in the cultural development and social organization of steppe peoples throughout history.

The Xiongnu imperial structure brought many changes to nomadic society in Mongolia, including increased diversity of food sources, protection provided by a formalized military organization, redistribution of people as a result of Xiongnu conquest, and installation of ethnically Xiongnu administrators across the Mongolian steppe.

Although the military structure of the Xiongnu Empire is well documented, the daily experiences of people living under Xiongnu rule are still poorly understood. Critical questions remain to be explored, including the impact of these social and political changes on the health and welfare of the Xiongnu population. In this dissertation, skeletal remains of Xiongnu nomads were analyzed to determine the impact of the creation of the Xiongnu Empire on the health, diet, distribution, and composition of its members. In addition, skeletal material attributed to the Mongolian Bronze Age (ca. mid-2nd to mid-1st millennium BC), and skeletal material of an early Iron Age sedentary agricultural population in Qinghai province, China living under the control of the Han Empire were included in this study.

Much of what we currently know about the Xiongnu Empire comes from Chinese-centric historical sources, most notably the *Shiji* (史記) and *Han shu* (汉书). There are no extant documents written by the Xiongnu themselves. All written sources available today were written by Chinese historians during the Han period (3rd century BC to AD 3rd century) who take a decidedly negative view of their northern neighbors, emphasizing the destructive influence of the Xiongnu on the northern frontier. The nomads of the steppe first appear in Chinese historical records during the fourth century BC and very little written information is available about them before this time (Barfield 1989:32).

The *Shiji* (史記) (Sima 1959) and *Hanshu* (汉书) (Ban 1962) are two ancient Chinese court histories that provide most of the information we have today about the society and culture of the Xiongnu. Both texts include biographies of important figures, accounts of events, and treatises on important topics of the times. Despite their potential historical biases and inaccuracies, these documents provide crucial insight into the political, military, and social organization, customs, and practices of the ancient nomadic tribes of Mongolia.

The Xiongnu Empire (c. 209 BC to 200 AD) is a political entity comprised of ethnically diverse groups and is mainly defined by continuity in material culture and burial architecture, so a review of archaeological data is crucial for determining the boundaries of the Xiongnu sphere of influence on the steppe. Xiongnu cemeteries span the entirety of the Mongolian steppe, from the high passes of the Mongolian Altai in the west to the grasslands of Manchuria in the east, and from the Trans-Baikal region of southern Siberia in the north to the Ordos Loop in present-day Inner Mongolia (see Figure 2.1; Honeychurch and Amartuvshin 2005:256-257).

These cemeteries include graves with varying levels of architectural complexity, degree of labor investment in tomb construction, and amount and quality of grave goods. They represent the burials of individuals from the full socioeconomic spectrum of Xiongnu society, from elites to slaves. Published archaeological reports on Xiongnu-period excavations provide context for the skeletal remains analyzed in this study and additional material to help interpret the results of the bioarchaeological analysis.

Incorporating historical records and cultural material related to the Xiongnu into this research helps determine the underlying causes for any changes or patterns observed from the bioarchaeological analysis. By using multiple lines of evidence, including archaeological, skeletal and textual sources, the biases of each of these categories of data are minimized.

1.2. Bioarchaeological Methods and Research Objectives

Bioarchaeological analysis of human skeletal remains can provide direct evidence of the health and diet of people in the past. Analysis of the morphological features of human bone can provide evidence pertaining to many aspects of physical health including rates of accidental or intentional trauma, infectious and degenerative diseases, nutritional deficiencies, physiological stress, dietary changes and composition, relatedness between different ethnic groups, and migration of people. These data are used to independently test theories of the formation of, and interaction within, the Xiongnu Empire.

In the present study, data acquired through examination of human remains are used to investigate the health consequences of the establishment of the Xiongnu Empire. The study sample includes observations of 349 individuals from 27 archaeological cemetery sites dating from the Bronze Age to early Iron Age. These sites are distributed across Mongolia (Western, Central, and Eastern), in addition to one site located in the northwestern Chinese province of Qinghai. The diversity of this skeletal sample represents individuals from the entire region under Xiongnu control.

The spatial and temporal distribution of the sites included in this dataset allowed changes in health during the period of Xiongnu control to be examined, as well as how these changes may have differed in peripheral regions of the empire. The broad spatial distribution of sites also made it possible to investigate the movement or displacement of Bronze Age groups during the transition to the imperial structure of the Xiongnu period. The inclusion of a Chinese sedentary agricultural frontier settlement that was in use contemporaneously with Xiongnu rule on the steppe allowed conditions that arise from leading a pastoral nomadic lifestyle to be distinguished from conditions that can be attributed to the sociocultural changes that accompany the formation of the Xiongnu Empire.

I hypothesize that dietary changes will result in a decline in the overall health of subjects of the Xiongnu Empire compared to the health of individuals of the Bronze Age. I also expect the ethnic makeup of local populations to change as people move, either voluntarily or involuntarily, across the steppe, and as interactions between previously isolated tribal groups occur in response to the implementation of Xiongnu rule. I also argue that differences in health and diet will be evident among the Xiongnu people based on their proximity to the core of Xiongnu power in central Mongolia. Those closer to the core (elites) may have had increased access to Chinese goods such as millet, which should be reflected by a health status resembling the agricultural Chinese individuals examined. As a result of political restructuring and conquest, I hypothesize that ethnically Xiongnu people moved from the core across the Mongolian steppe and that some non-elite ethnic groups were displaced from their Bronze Age homelands to new locations during the Xiongnu period.

1.3. Dissertation Structure

Chapter 2 provides some ecological and environmental context of the research area, followed by the history of the Xiongnu as understood from ancient texts written by Chinese historians. A review of previous archaeological studies of Mongolian steppe groups during the Bronze and Iron Ages concludes this chapter. Chapter 3 gives an overview of empire and state formation theory and some models that have been applied to the creation of the Xiongnu polity. The research questions and hypotheses explored in this study are also described in Chapter 3.

Chapter 4 discusses the bioarchaeological models and correlates that are used to address the research questions in this study. This research project involved careful study of human skeletons from three populations: Mongolian Bronze Age nomads, Xiongnu people, and Han dynasty Chinese agriculturalists. A description of the sites that make up this study sample, including their archaeological context and how they were chosen for inclusion in this study, are provided in Chapter 5. Chapter 6 describes the categories of data gathered for this study and the bioarchaeological methods of data collection and analysis.

The results of the data analysis are presented in Chapter 7. These results include demographic profiles and comparisons of several variables between groups by site, region, subsistence strategy, and time period. Chapter 8 contains a discussion of these results, their implications for revisiting existing theories of the formation and inner workings of the Xiongnu Empire, and how these results answer the research questions set forth for this study. Chapter 9 will place the significance of the present research in the context of Xiongnu studies and empire studies in general, as well as present some suggestions for future research in these areas.

The research presented in this dissertation is a detailed study of the physical and biological impacts of the transition to an imperial organization of nomadic tribes during the Xiongnu period. These results will help refine theories of nomadic empire formation and provide insight into the effects of the Xiongnu Empire on the day-to-day living conditions of its subjects.

Chapter 2: Environmental, Historical, and Archaeological Context

2.1. Introduction

The goal of this dissertation is to explore the health, diet, and demographic changes associated with the establishment of the Xiongnu confederacy. The bioarchaeological analysis of archaeologically recovered skeletal remains of Xiongnu individuals provides a data set to complement historical and archaeological investigations on this topic. This study is designed to use these bioarchaeological data to independently test and reassess theories of nomadic empire formation and organization. The perspective gained by approaching these questions through bioarchaeological data brings new insight to Xiongnu and empire research.

Xiongnu studies are greatly enhanced by historical and archaeological data. The Xiongnu first appear in Chinese historical documents dating to the early 4th century BC, but archaeological evidence suggests that contact between China and the nomads of the Mongolian steppe began around the 8th century BC (Barfield 1989; Di Cosmo 1999, 2002). Most of the information currently available on Xiongnu culture and political structure comes from Chinese texts, particularly chapters in the *Shiji* (Records of the Historian) and *Han shu* (History of the Former Han). These accounts are official Chinese histories, and as such must be evaluated critically in their portrayal of Xiongnu life. These detailed histories contain information about the social customs of northern nomadic groups, military organization, economy, trade, and Chinese-nomad relations. There are no extant written documents created by the Xiongnu themselves.

The wealth of archaeological material from the Xiongnu period is mainly found in burial contexts. These materials balance the Chinese-centric perspective of the written histories. These two lines of evidence, textual and archaeological, complement the bioarchaeological data that form the basis of the present study.

This chapter provides an overview of the historical records pertaining to the Xiongnu and an archaeological survey of the time periods relevant to this dissertation project. The time periods included in this chapter are the Neolithic, Bronze Age, and Iron Age in greater Mongolia and the frontier zone of northern China. Particular focus will be on the early Iron Age Xiongnu period of the Mongolian steppe region (200 BC – AD 200).

The sites from which samples were selected for this study are located across Mongolia and northern China, an area known as the eastern Inner Asian steppe. This region contains several ecological zones and diverse geographic features. Before a discussion of the history and archaeology of the study area, a brief overview of the environmental conditions in this region is provided.

2.2. Environmental Context

The Central Eurasian steppe refers to an area stretching from eastern Europe into northeast Asia and encompasses a range of environmental zones. The Mongolian steppe at the eastern end of this zone contains lake and river systems, mountain ranges, deserts, and a variety of steppe vegetation (Figure 2.1). Mongolia forms a plateau above the surrounding areas, with an average elevation of 1,580 m above sea level (Goulden et al. 2011:88). Three major mountain ranges cross this plateau; the Altai Mountains that run along the western border between Mongolia and China, the Sayan Mountains in the northwest, and the Khangai mountains in central western Mongolia. Taiga forests with permafrost extend from Siberia into northern Mongolia, while southern Mongolia is characterized by semiarid grassland and desert. Almost 80% of Mongolia is covered by steppe grasslands. The Gobi desert, which covers southern Mongolia, extends southward into the Chinese province of Inner Mongolia (Figure 2.2).

Figure 2.1. Map of East Asia with modern political borders. Study area is demarcated by the inset black border (Google Maps 2015).

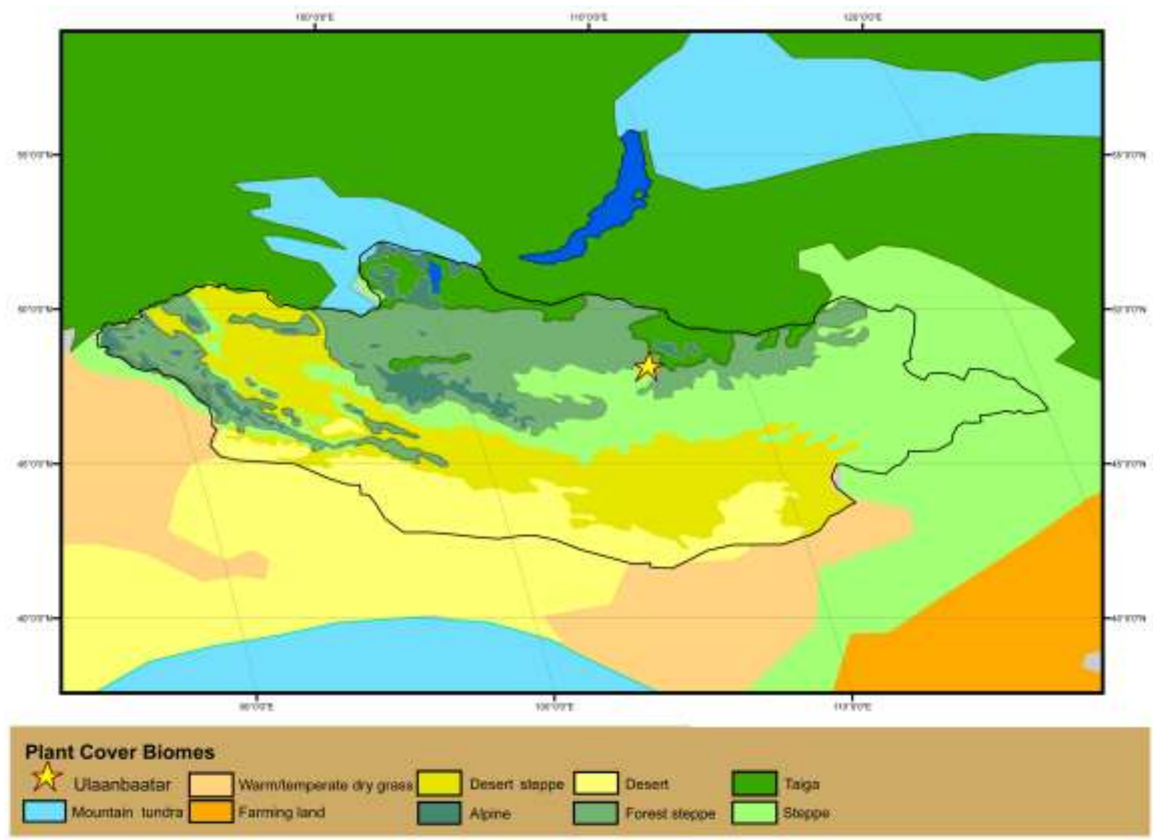


Figure 2.2: Ecological zones of Mongolia (modified from original by Dennis Murphy; Goulden et al. 2011:92, Figure 5.4).

The altitude and northern latitude of Mongolia account for the extreme climate fluctuations found there. The changes in elevation between the western mountainous regions and the lower steppe grasslands in the east create significant thermal gradients and heavy winds that can cause drastic changes in temperature (Goulden et al. 2011:91). The Mongolian steppe has very long dry winters, with temperatures as low as -60º F and short moist summers when temperatures can exceed 100 º F.

Mongolia receives only 230 mm of precipitation annually, on average. About 90% of this precipitation falls between April and September, with the heaviest rainfall occurring in July and August. Snowfall accounts for only 20% of total annual precipitation. Winter storms are rare, but *dzuds*, winters with abnormally cold temperatures or heavy snowfall, can be extremely disastrous. *Dzuds* can create snow cover and ice crusts that prevent livestock from reaching winter forage.

The aridity and climate of Mongolia are not well suited to agriculture, which was also the case during the Bronze and Iron Ages (Honeychurch and Amartuvshin 2005:256). In most areas the growing season is only about 100 days long. As early as the third millennium BC, people in this region had already adopted a variety of subsistence strategies to exploit the resources of the steppe, including hunting and gathering, fishing, and some small-scale agricultural production (Honeychurch and Amartuvshin 2005:259). Nomadic pastoralism, raising livestock by seasonal movement to different pasture, is the most successful and extensively practiced economic mode in Mongolia (Barfield 2011).

2.3. Historical Background

The Xiongnu confederacy is the first historically documented Inner Asian empire (Di Cosmo 2002). The Xiongnu Empire reached a sophisticated level of political and military complexity and is the best known example of a successful nomadic state. Scholars believe the Xiongnu are represented under a variety of different names in ancient Chinese records, including Xunyu (葷粥), Xianyun (玁狁), Rong (戎), and Di (狄). These may all refer to the Xiongnu (Wang 2014), but the only alternate name that is historically associated with the Xiongnu is Hu (胡) (Yü 1990). Historical knowledge of the Xiongnu begins around 300 BC from records written at the end of the Chinese Warring States period.

Wooden documents of the Han period from Dunhuang and the Edsen-gol region of present day Inner Mongolia have been published in Michael Loewe's two volume work *Records of Han Administration* (1967). The books present a detailed study of some of the Han wooden slip documents discovered during the 1920s and 1930s. A collection of about 900 Han document fragments were discovered by Sir Aurel Stein during his expeditions near Dunhuang. These fragments have dates placing them between 98 BC and 137 AD. A Sino-Soviet expedition that took place from 1927 to 1934 found approximately 10,000 wooden slip fragments at 21 sites along the lines of fortification in the Edsen-gol region (Academia Sinica 2014). The dates in these inscriptions fall between 102 BC and 98 AD. Another approximately 500 fragments of wooden documents were found in an Eastern Han tomb in Gansu province in 1959. Most of the original fragments are kept in the British Museum or in collections in China and Taiwan. More recently, wooden slip documents from a postal relay station at the site of Xuanquan in Gansu were discovered in the 1990s (Yang 2015). These documents illustrate some of of duties and transactions that low level officials in the Western regions of the Han Dynasty dealt with on a daily basis, which could include interactions with the Xiongnu tribes. Many of these documents contain receipts of the type and amount of goods, including grain, distributed by the Han government (Loewe 1961, 1967).

Generally, these bamboo slip documents do not refer to the Han central government or high level authorities. They include reports on the official mail system, lists of officers, records of weapons and equipment issued to military units, control of travelers, daily activities of servicemen, inspectors' reports on the condition and efficiency of the units in the garrison, incident reports, copies of imperial decrees and notifications, and calendars (Loewe 1961, 1967, 1973; Yang 2015). These documents may shed light on non-hostile transactions between the Han military garrisons and the surrounding nomadic groups.

The official Chinese histories that provide accounts of the Xiongnu include the *Shiji*, *Han shu*, and *Hou Han shu* (后汉书). The earliest of these is the *Shiji*, or Records of the Historian, written and compiled by Sima Tan and his son Sima Qian by 99 BC. This body of work set the standard for how subsequent histories would be arranged, and is the first document that describes the nomadic groups north of the Han Empire (Di Cosmo 2002). This text is made up of 130 chapters in five sections. Chapter 110 of the *Shiji* is the major source of information about the Xiongnu Empire. This description was aided by the personal recollections of Zhang Qian (張騫) who had lived among the Xiongnu as a captive for a decade. He was the first Han official to bring back first hand information about the Xiongnu to the Han court (Sima 1959, 1993).

The *Han shu* (Ban 1962) was compiled during the latter part of the first century and the first half of the second century AD by Ban Biao and his son, Ban Gu. This was the first official history to limit its scope to one dynasty. The chapter related to the

Xiongnu is an almost verbatim quotation of chapter 110 of the *Shiji* (Wylie 1874). The *Hou Han shu* (Fan 1965) was compiled by Fan Ye in the fifth century AD. This document relies on many earlier histories and texts, including the *Shiji* and *Han shu*.

Chinese sources report that the states of Qin (秦), Zhao (趙), and Yen (燕) each built a defensive wall along their northern borders to prevent attacks from nomadic tribes. Qin was the first to do so, around 324 BC, but the entire walled defense system was not completed until about 270 BC. The Great Wall of China, as we know it today with brick facing stones, was not unified into one wall until the 15th century AD during the Ming dynasty (明朝) (Di Cosmo 2006).

The Xiongnu had contact with the Zhao and Yan states, but Qin, which emerged as the most powerful state during the Warring States period (403 – 221 BC), posed the biggest threat to the Xiongnu tribes (Yü 1990). The Xiongnu were pushed into the Yin Mountains of the Ordos during the unification of China under the first emperor of Qin, Shi Huangdi (始皇帝). They were prevented from expanding southward for the next few years. Qin Shi Huangdi expanded and unified the three defensive walls in 270 BC. The implication that all of the northern nomads were the enemy, materialized in the unified wall between the Chinese states and the steppe, may have fostered a sense of solidarity among the tribes and aided in the development of the Xiongnu Empire (Yü 1990).

The parallel accounts in the *Shiji* and *Han shu* describe the Xiongnu as vicious barbarians that move with their herds and have no permanent cities. They learn to ride and shoot arrows from horseback from an early age. They do not follow Chinese customs of honor in battle or value filial piety (Sima 1993:129). Little is known about the religious beliefs of the Xiongnu. Passages in the *Shiji* mention sacrifices to the gods, and ancestors, as well as daily rituals performed by the *chanyu* (单于) to honor the sun and moon (Sima 1959, 1993:137). The account also describes the founding of the Xiongnu Empire by Maodun (冒顿), and the military and political organization of this new state.

The historical account of the formation of the Xiongnu Empire, as written in the *Shiji*, begins with the first ruler (*chanyu*) Maodun, who usurped control of the Xiongnu tribe from his father Touman (头曼) in 209 BC (Sima 1959, 1993:134-136). After gaining control of his own tribe, he amassed an army and reclaimed the land to the south that had been lost to the Qin emperor. In 206 BC, Maodun defeated the Donghu (东胡) to the east and captured people and property. The Donghu came under the control of the *chanyu* and were forced to send him tribute every year. The Xiongnu pushed the Yuezhi (月氏), the tribe to their west, out of the Gansu corridor and occupied that territory. Next, they conquered sedentary, agricultural states in the Tarim basin, referred to in Chinese texts as the Western Regions. Xiongnu control in this region strengthened the political and economic foundation of the empire. A new political office was established to govern these western states. The Xiongnu collected labor and goods from the Western Regions (Di Cosmo 2002:197-198).

In the organization of the imperial confederation, the *chanyu* was the political and military leader who also served as the sole intermediary between the Xiongnu tribes and the Chinese empire. The rest of the political hierarchy was organized according to a decimal-based military structure. The “Tuqi” (屠耆) Wise Kings of the Right and Left (positions directly subordinate to the *chanyu*) controlled the west and east areas of the Xiongnu territory, respectively. Under these positions generals, commandants, and various other administrative positions were appointed by the *chanyu*. Often these officials were chosen from the *chanyu*’s own lineage group and the Wise King of the Left appointment was usually given to the *chanyu*’s heir. The twenty-four highest officials were given the title [Chiefs of] Ten Thousand Horsemen, referring to their responsibility to muster ten thousand mounted warriors when necessary. These high officials occupied a hereditary position and had the authority to appoint local chiefs. At the local level, social organization remained much as it had been before the Xiongnu unification.

The foundation of the *chanyu*’s power was his ability to acquire grain, wine, silk and other exotic or luxury goods not generated by pastoral production from external sources, such as the Chinese empire to the south and oasis states in Central Asia. His position was justified by his ability to provide a benefit to the rest of his imperial administrators and local leaders (Barfield 2001a:17-18). The Xiongnu would organize raids into the Chinese frontier to extort goods, but at no time did they attempt to occupy Chinese territory (Barfield 1989:49).

After a brief civil war that dissolved the Qin dynasty, the Han dynasty (漢朝) emerged in China in 206 BC under emperor Gaozu (高祖). In 201 BC Gaozu, fearing that his northern borders were being threatened, attacked the Xiongnu and suffered an embarrassing defeat. The emperor and his army were surrounded by Xiongnu cavalry and Gaozu was forced to seek a peace treaty between the Xiongnu and Han Empires (Sima 1959, 1993:138-139).

The *heqin* ("peace marriage," 和親) policy was a way for the Han to buy peace with the Xiongnu in exchange for goods (Yü 1967:10). The terms of the treaty required the Han to send an imperial princess to the *chanyu* in marriage, to formally acknowledge the Xiongnu Empire as a political equal, and to present gifts of silk floss, textiles, wine, and millet to the *chanyu* several times per year. In return, the Xiongnu would refrain from attacking Han lands (Sima 1993:139-142; Yü 1990:119).

Modun periodically "renegotiated" the terms of the alliance by threatening to raid Chinese frontier settlements if the amount of tribute was not increased. Modun died in 174 BC and his next few successors took an aggressive course of action toward the Chinese empire. The subsequent *chanyus* led raids against Chinese settlements and generally disregarded the terms of the *heqin* agreement. The Xiongnu would periodically resume attacks on Chinese border settlements in order to extract higher tribute payments from the Han government (Sima 1993:145).

The Han emperor eventually revised the terms of the treaty because of the continued attacks. The amount of tribute to the *chanyu* was increased and border markets were opened, allowing trade between the nomads and frontier villages. Official histories often do not include accounts of non-sanctioned trade across the Chinese-Xiongnu border. One passage from the *Han shu* mentions the establishment of border markets as a condition of the renewal of the *heqin* treaty. Despite occasional interruptions, markets were opened at the Great Wall to allow trade directly between the Xiongnu and Chinese people. These border markets attest to the relative peace between the groups and the attachment of the Xiongnu to Chinese goods. When this avenue of trade was cut off, the Xiongnu resorted to raiding to get the supplies they needed from their Han neighbors. By 157 BC, regular contact occurred between the Xiongnu tribes and the Han people along the Great Wall (Di Cosmo 2006; Jagchid 1989).

Despite the insult of being relegated to a position of political inferiority by a "barbarian" empire, the *heqin* policy remained in effect for decades, but the treaty became increasingly expensive to honor as time passed. In addition to the expense, the Xiongnu did not always comply with the terms of the treaty, so the Han court eventually had to find another way to deal with the Xiongnu.

The shift from a policy of appeasement to one of military aggression toward the Xiongnu began with the reign of Han Wudi (汉武帝) in 140 BC. The relatively peaceful relations maintained by the *heqin* policy between these two powers was abandoned in favor of a military campaign against the Xiongnu in 133 BC, bringing an end to this period of stability along the frontier (Sima 1993:149).

As part of his offensive strategy, Wudi sent envoys into the Western Regions to establish relations with the oasis states, cutting off Xiongnu access to resources from the west. The cancellation of the *heqin* policy and the drawn out fighting against Han military forces took a toll on the Xiongnu and eventually led to a civil war in 60 BC.

After a decade, the Xiongnu were reunited. During the split, the southern *chanyu* had surrendered to China and entered into the tributary system, which in reality was not much different than the old *heqin* policy. The Xiongnu were able to manipulate the new tributary system to receive large amounts of goods from China (Barfield 1989:62-63). The confederation was able to survive the brief Xin (新) Dynasty founded by Wang Mang (王莽) from AD 9-23, only to succumb to a second Xiongnu civil war in AD 46. The Xiongnu factions did not reunite, leaving the steppe fragmented for the first time in over 250 years (Barfield 1989:67-80).

2.4. Cultural Overview and Survey of Archaeological Research

2.4.1. Introduction

By reviewing the material remains of pastoral groups in Mongolia from the late Bronze Age (late first millennium BC) through the Iron Age Xiongnu period (second century AD) we can contextualize the stage upon which the present research is situated and understand the changes in social organization and culture leading in to the supra-tribal Xiongnu polity. The survey of archaeological material presented in this chapter also includes relevant research conducted in areas surrounding Mongolia including southern Siberia and northern China.

2.4.2. Transition to the Bronze Age

As early as the third millennium BC, people living across the Mongolian steppe had adopted a variety of subsistence strategies to take advantage of available resources including small-scale agriculture, hunting and gathering, and fishing (Honeychurch and Amartuvshin 2007; Machicek 2011). During the second and early first millennium BC pastoral herding of domestic animals, namely goats, sheep, and horses, became a major subsistence strategy in the Mongolian steppe and by the early first millennium BC nomadic herding societies occupied much of the Eurasian steppe (Honeychurch and Amartuvshin 2005:259; Kovalev and Erdenebaatar 2009:150-152).

Nomadic pastoralism spread into the Mongolian steppe from the west over thousands of years and brought with it a suite of technological innovations including the domesticated horse (Levine 1999), adoption of wheeled vehicles and chariot technology, bronze metallurgical technology (Kohl 2007:168), and development of burial rituals and animal sacrifices (Anthony 1998:94). It is generally thought that this shift to mobile pastoralism in western and central Asia was preceded by an agricultural and sedentary way of life (Allard and Erdenebaatar 2005:547; Shelach 2009).

The nomadic people of the Altai Mountains have relied on horses as the basis of their economy for millennia. The horse was first domesticated around 6000 BC and horse riding began by about 4000 BC (Anthony and Brown 1991). Horses were bred locally after their introduction from the Near East, and were the preferred method of transportation in Central Asia by 1000 BC (Clutton-Brock 1992). Horse riding drastically changed the way of life in the Altai region. Herds of animals could be managed more easily from horseback, and horses themselves were a source of meat, milk products, and hides.

2.4.3. Bronze Age

From the mid- to late-second millennium BC until the mid-first millennium BC, a period that roughly corresponds to what archaeologists define as the Bronze Age in Mongolia, significant cultural changes are evident in the archaeological record. Bronze Age Mongolia is characterized by two distinct cultures with unique burial styles (Figure 2.3). The *khirigsuur* culture, named for the mounded stone monuments and burials that are prominent features of ritual sites, dominated the western steppe. The slab grave culture, predominantly located in the eastern steppe, had a significant area of overlap with sites of the khirigsuur culture in central Mongolia. Russian scholars (Tsybiktarov 2003) propose a third cultural group, occupying an area of southern Siberia and north-central Mongolia. This group had less geographic overlap with the *khirigsuur* and stone slab grave cultures. These groups, defined by the burial styles and monuments they employed, are undoubtedly an oversimplified representation of the complex interactions of people living on the Mongolian steppe during the Bronze Age. Nonetheless, these definitions help us identify and compare differing traditions in material culture during this period.

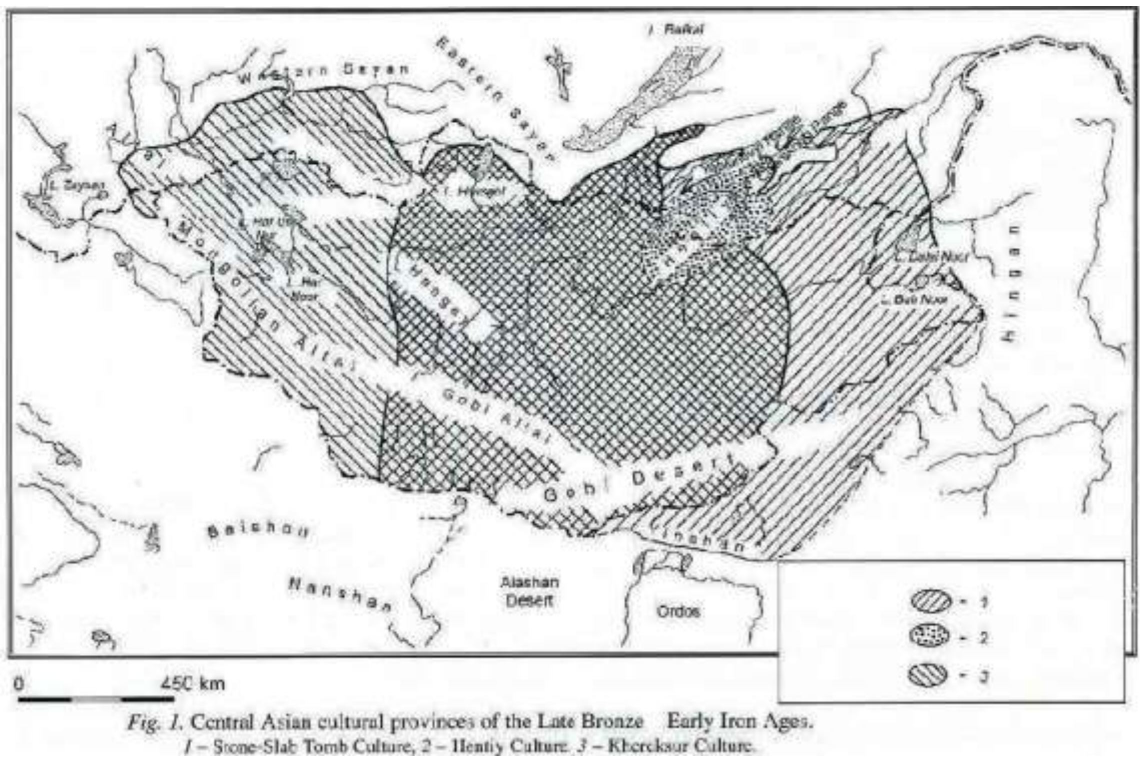


Figure 2.3. Bronze Age cultures of Mongolia (Tsybiktarov 2003).

The cultural complex of *khirigsuur* ritual sites, comprised of stone mounds enclosed by circular or square stone fences, and deer stone megaliths with depictions of flying deer and human features and accessories becomes prolific during this period (Figure 2.4). The spatial distribution of these structures overlaps in some areas, particularly in central Mongolia. Although these features can appear together at single sites, the temporal and functional connections between them are still unclear (Allard and Erdenebaatar 2005:547).

Recent research suggests that the *khirigsuur* complexes date to the late second millennium BC, which precedes the slab burial culture (Erdenebataar 2002; Fitzhugh and Bayarsaikhan 2008; Wright 2006). Surveys of *khirigsuur* complexes (Wright 2006, 2007) show that the features of these monuments display a high level of homogeneity in central Mongolia, but become more variable further west. Slab graves were sometimes constructed on the periphery of *khirigsuur* complexes, suggesting that they were placed to take advantage of the established ritual structures.

Figure 2.4. Deer stone megalith with *khirigsuur* complex in the background, Tsagaan Asgat, western Mongolia (University of Oregon Department of Art History 2009).

The stone slab grave culture of eastern and central Mongolia is believed to be the group most closely related to the Iron Age people of Mongolia (Torbat 2006) and is the most significant cultural group in this region preceding the Xiongnu polity (Dikov 1958; Erdenebaatar 2002; Miller 2009; Navaan 1975; Tsybiktarov 1998). Survey data indicate the slab grave culture dates to the early-mid first millennium BC (Torbat et al. 2003; Wright 2006), which temporally and spatially overlaps the *khirigsuur* complex culture.

The slab burials that define this culture consist of shallow pits lined with flat, rectangular stones, usually containing a single individual (Figure 2.5). Often, animal remains are buried with the individual, including the heads, hooves, and lower limbs of horses, sheep or goats. Grave goods include bronze knives, arrowheads, and mirrors, horse riding accoutrements, and various personal accessories (Miller 2009:190). "Pie crust" rimmed ceramic vessels are the most distinctive items found in stone slab burials and are used as a diagnostic artifact in determining the relative dates of settlement sites found during survey (Houle 2009; Miller 2009; Wright 2006).

Figure 2.5. Slab grave, Khanuy Valley, central Mongolia (Miller 2009:189).

Slab graves have modest surface demarcations and are usually only a few meters in diameter. Sites contain a few or even a single burial (Honeychurch 2004; Torbat et al. 2003; Wright 2006). Age and sex distribution of the individuals excavated from slab graves indicate that these burials represent the entire population of a particular social stratum within this society (Miller 2009:191; Wright 2006:276).

Kurgan culture sites span the Russian and Mongolian Altai and the area around the central Mongolian border with Siberia (Amgalantogs et al. 2007; Rudenko 1970; Semenov 2003; Tseveendorj 1980). These sites range in date from the second millennium BC to the late first millennium BC. Kurgan sites have been attributed to several cultures – Pazyryk culture, named for the type site of Pazyryk in the Russian Altai (Rudenko 1970); Chandman culture, after the type site in northwestern Mongolia (Tseveendorj 1980); and the Uyuk culture of Tuva (Mannai-Ool 1970). Despite these various names, the kurgan culture of north-central Mongolia and surrounding areas exhibits features distinctly different from those of contemporaneous cultures in other areas of Mongolia.

The kurgans are burials with stone mound surface markers from one to ten meters in diameter. The burial pit usually contains a small stone cist, often containing more than one individual. One burial may contain any combination of men, women, and children. The body is most commonly placed in a flexed position.

At Pazyryk, Chandman, Uyuk culture sites, larger kurgans with log construction burial chambers have been excavated (Rudenko 1970). Some of these larger kurgans have wooden burial chambers beneath the stone mound on the surface. On the surface, these kurgans consist of mounds covered by stones. Beneath the mound is a rectangular shaft with a log chamber placed at the bottom. The burial chamber contains the human interments and grave offerings. Horse burials are located in the northern part of the shaft, outside the log chamber. These elaborate tombs illustrate the lavish burial rituals that had been established in these cultures to display the power and wealth of their elites.

The late Bronze Age and early Iron Age of the northern China frontier is characterized by three main cultural groups, named after the type sites of Maoqinggou, Taohongbala, and Yanglang.

Maoqinggou is located north of the Ordos loop of the Yellow River in Inner Mongolia. This site was in use up to the fourth or third century BC. During the earlier phases of the cemetery, the burial style, body orientation, and grave good assemblages are mixed. In the last phase of use however, the burials become more homogeneous. These later graves often include animal offerings and a different style of ceramics, which support the theory that a shift from an agricultural to predominately pastoral way of life took place at this time (Nei Menggu zizhiqu wenwu gongzuodui 1986:303-304).

Taohongbala lies within the Ordos loop of the Yellow River in Inner Mongolia. This cultural group includes the lavish burials containing elaborate gold jewelry and ornaments at sites like Aluchaideng (Tian and Guo 1986) and Xigoupan (Yikezhaomeng 1980, 1981; Tian and Guo 1986). The cemeteries of the Taohongbala group contain very few burials per site.

The site of Yanglang is situated on the eastern edge of the Gansu corridor in China’s Ningxia province. The Yanglang cultural group includes many sites, but none are in use after the third century BC (Tian and Guo 1986).

The diversity of cultural practices in various regions across the steppe in the late Bronze Age – khirigsuur culture of western Mongolia, kurgan cultures of northern Mongolia and southern Siberia, slab grave culture in eastern Mongolia, and the northern Chinese frontier groups – give way to a more homogeneous burial and material culture tradition by the second century BC.

2.4.4. Iron Age

By the end of the first millennium BC, the small-scale societies scattered across the Mongolian steppe were organized into a hierarchical, integrated, militaristically oriented polity. The Xiongnu confederation of nomadic tribes ruled most of the Mongolian steppe from 209 BC to AD 93. At the height of their power, the Xiongnu controlled, either directly or indirectly, a territory that spanned the Inner Asian steppe from Manchuria to Kazakhstan, from the Lake Baikal region of southern Siberia into Inner Mongolia in present-day northern China, and into the Tarim Basin (Honeychurch and Amartuvshin 2005:262-263). The ethnic affiliation of the Xiongnu lineage is unknown, but their original homeland was probably located near the Ordos loop of the Yellow River (Barfield 1989:33). This supra-tribal organization under the Xiongnu elite is linked to a high level of uniformity in burial style, ceramics, ritual, and grave goods.

2.4.4.1. Xiongnu Cemeteries

There are around 100 known Xiongnu cemetery sites across the Mongolian steppe, with an average between 10-50 burials per site (Figure 2.6). Analysis of nuclear and mitochondrial DNA from 49 tombs at Egiin Gol, Mongolia reveals that burial patterns may have been based on patrilineal kin groups (Keyser-Tracqui et al. 2003:258-259). Egiin Gol cemetery, located north of Ulaan Baatar, was in use from the third century BC to the second century AD. Despite the long period over which this cemetery was used, only 104 burials were found. This suggests that only a certain segment of the population was buried in this cemetery. The study found that closely related individuals (parents and children, siblings, etc.) were buried near each other, and in one distinct area of the cemetery, all the male individuals were from the same patrilineal group. The family ties that are evident in the burial pattern at Egiin Gol were probably important during the lives of these individuals. The differential patterns of burial at Egiin Gol and other cemetery sites suggest that a sophisticated social hierarchy existed in Xiongnu society (Honeychurch 2006).

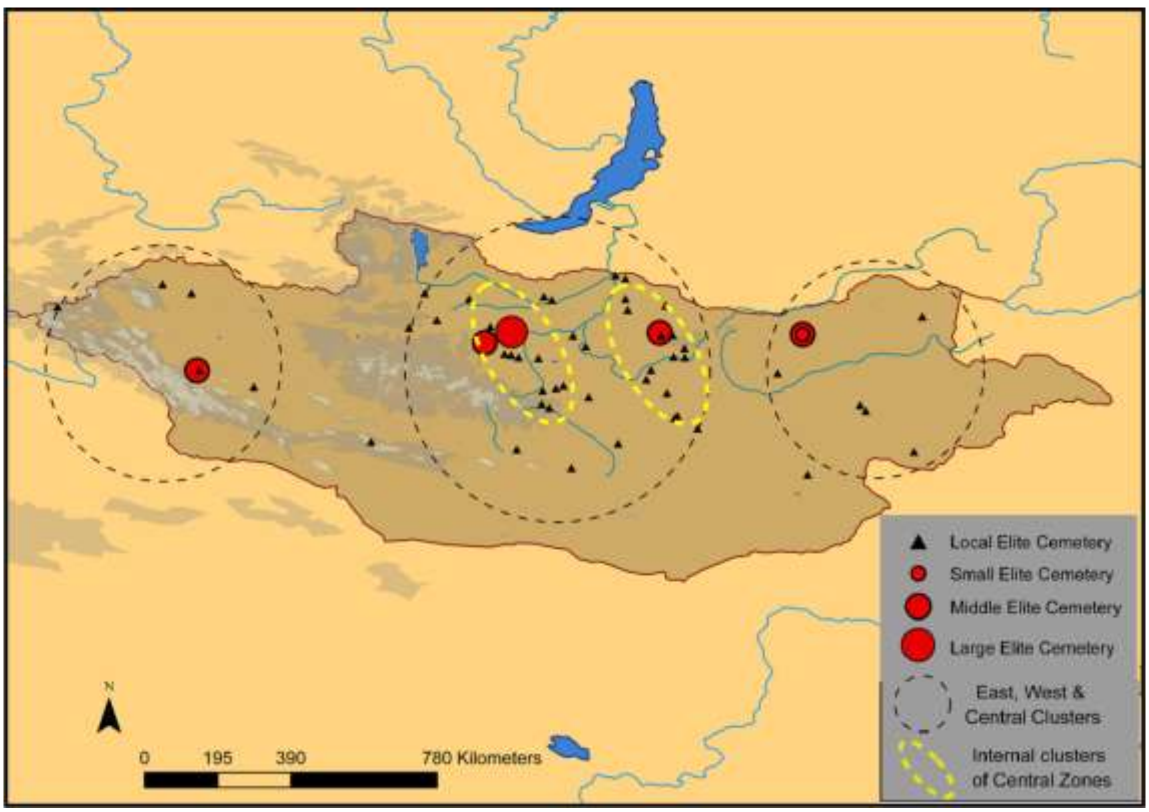


Figure 2.6. Locations of elite Xiongnu cemeteries in Mongolia (after Honeychurch and Amartuvshin 2011:212, Figure 9.5a, b).

Xiongnu funerary practices also give us an indication of social structure. Aside from monumental tombs, the most common graves were relatively small and consisted of round or rectangular stone mounds (So and Bunker 1995). Differentiation in tomb size and amount of grave goods indicates the society was socially stratified. Most grave goods are utilitarian in nature and easily portable, which would be expected in a nomadic society.

2.4.4.2. Tomb Architecture

Xiongnu tombs fall into two main types – circular stone mound graves and large square ramped tombs. Circular stone mound tombs are the most common type of Xiongnu burial. Burials with small stone cluster surface markers have also been found. These stone cluster burials are usually in close proximity to a larger circular stone mound or square mound tomb (Miller et al. 2008, 2009). Circular stone mound burials usually contain stone cists or wooden coffins inside the burial pit. This style of burial becomes common in the second century BC and tapers off during the second century AD (Miller 2009:295).

Monumental square ramped tomb complexes appear in Xiongnu cemeteries in the late first century BC and fall out of use in the first century AD. The square ramped tomb mounds are oriented roughly north-south and are surrounded by stone walls. A stone ramp extends from the southern wall from the top of the mound (Figure 2.7). Beneath the mound lies a wooden burial chamber containing a decorated wooden coffin and grave goods.

Figure 2.7. Square ramped tomb at Takhiltin Khotgor cemetery (Tomb 64, Mongol-American Khovd Archaeology Project 2007).

Coffin decorations are found in both circular stone mound and square ramped mound tombs. Wooden coffins may be decorated with lattice and quatrefoil designs made of metal or wood (Figure 2.8). In some instances the coffin is wrapped in textile and the lattice decoration is attached to the textile shroud. Wooden coffins are sometimes painted with the lattice and quatrefoil motifs (Miller et al. 2009).

Figure 2.8. Lattice and quatrefoil decorations on Xiongnu coffins. Top: gold with inlay (Gol Mod); middle (from left to right): iron (Burkhan Tolgoi), birch bark (Burkhan Tolgoi), and iron (Takhiltiin Khotgor); bottom: reconstructed gold lattice and quatrefoil decoration (Duurlig Nars), National Museum of Mongolia (Eregzen 2011:69-71).

Circle and crescent decorations, representing the sun and the moon, have been found in several tombs as part of the burial furnishings. These decorations are usually constructed of iron or gold (Figure 2.9). One large ramped tomb at Takhiltin Khotgor cemetery in western Mongolia contained a gold foil sun and moon among the grave goods (Miller et al. 2008:30). The position of these decorations within the burial chamber suggests that they would have been affixed to the head of the coffin.

Figure 2.9. Sun and moon coffin decorations in gold foil from Gol Mod cemetery (left), and iron from Burkhan Tolgoi (right), National Museum of Mongolia (Eregzen 2011:66-67).

Satellite burials adjacent to the ramped tombs have been discovered at several elite cemeteries in central Mongolia and around Lake Baikal in southern Siberia (Allard et al. 2002; Miller et al. 2006; Miniaev and Sakharovskaia 2002). These satellite burials are usually marked on the surface by a small stone mound or ring. On average, each tomb complex includes three satellite burials, usually arranged in a north-south arc to the east, west, or both sides of the ramped tomb (Miller et al. 2007:28). The individuals in these burials are sometimes interred within stone cists (Figure 2.10, Miller 2008:31) while others have no coffin at all (Jones and Joseph 2008:37).

Figure 2.10. Satellite burial of tomb 64, Takhiltiin Khotgor (Mongol-American Khovd Archaeology Project 2007).

Stone lines are the most recently discovered feature of Xiongnu tomb complexes (Allard et al. 2002). At Takhiltin Khotgor, eight square ramped tombs were found with east-west oriented stone lines parallel to the northern wall of the ramped tomb. These lines consist of paired stones, some of which have deposits of burnt crushed bone between them (Miller et al. 2007:33). It appears that these burnt bones are placed between the stone pairs as part of a burial or memorial ritual that occurs over time (Miller et al. 2007:34).

2.4.4.3. Xiongnu Assemblages of Grave Goods

Three main types of ceramics are found in Xiongnu graves. Large narrow-mouth vessels, large and small wide-mouth vessels, and open flat rimmed vessels (Miller 2009:210). To a lesser degree serving vessels such as cups, bowls, and jugs with handles or spouts are represented in the ceramic assemblage (Figure 2.11). Some of these ceramics show evidence of burning, indicating that they were used for cooking. Some vessels have been found with perforated bottoms, which may have been used for steaming food. Other vessels were used for storing or processing grain or beverages. In tombs at the site of Noin Uul in central Mongolia, remains of grain were found in ceramic pots (Rudenko 1962). Another type of small ceramic pot is found almost exclusively in burials. They share the form of the larger wide- and narrow-mouthed vessels, but are too small to have been of practical use and are often found in sets of five or six. These vessels may have had a ritual use and were created to imitate similar vessels that would have been used in life (Miller 2009:215). Footed cauldrons with loop handles are the typical form of bronze and iron vessels found in Xiongnu tombs (Figure 2.12; Davydova 1995; Torbat et al. 2003). The ceramic assemblages found at settlement sites are similar to those from burial contexts.

Figure 2.11. Examples of ceramic vessels from Xiongnu burials (top: Burkhan Tolgoi, bottom left: Tevsch Uul, bottom right: Tamiriin Ulaan Khöshöö), National Museum of Mongolia (Eregzen 2011:154-155, 162).

Figure 2.12. Examples of bronze vessels from Xiongnu burials (top left: Burkhan Tolgoi, top right: Takhiltiin Khotgor, bottom left: Duulga Uul, bottom right: Emeel tolgoi), National Museum of Mongolia (Eregzen 2011:169, 176-178).

The assortment of personal items found in Xiongnu tombs reflects the influence of a nomadic pastoral lifestyle. Weapons, tools, jewelry, and other small ornaments are commonly included in burials. The arrowheads found in Iron Age Xiongnu graves are larger and of different styles than their Bronze Age counterparts. These arrowheads were usually made from bone, bronze, or iron (Figure 2.13). The trefoil style arrowhead is most common, but the triangular and heavy tapered trefoil arrowheads are also found in burials (Khudjakov 2005). These different arrowheads would have all been carried by any one archer for various purposes. Bone bow plates, which were used to reinforce wooden bows, are also commonly found in burials. Spearheads, swords, and daggers comprise a very small proportion of weapons found in Xiongnu period burials.

Figure 2.13. Iron arrowheads from Burkhan Tolgoi (National Museum of Mongolia Eregzen 2011:239).

Sheep ankle bones, called astragali, are often found in burial contexts. These bones were used as gaming pieces during the Xiongnu period, and are used in Mongolia even today (Holmgren 2004; Kabzinska Stawarz 1983, 1985, 1991). Some astragali found in Xiongnu tombs have engraved markings. They are usually found near the waist of the interred individual and were probably carried in a pouch hung from a belt.

Belt plaques are a well known and researched Xiongnu artifact. They often contain detailed images of animals, human figures, or geometric designs (So and Bunker 1995). Some belt plaques are decorated with gold gilding and inlays of precious metals or stones (Figure 2.14). These ornate and ostentatious belt plaques served as a visible marker of status among steppe elites (Miller 2009).

Figure 2.14. Belt plaques from Xiongnu burials. Left: gold foil with inlay, right (top and bottom): iron. Burkhan Tolgoi. National Museum of Mongolia (Eregzen 2011:138, 140).

Chinese bronze mirrors and Central Asian imitations of Chinese-style mirrors are another elite item found in Xiongnu tombs across the steppe at sites such as Noin Uul, Pazyryk, and Gol Mod 2 (Miller et al. 2006; Miller 2009; Rudenko 1962, 1970). These mirrors vary in form and decoration, from simple ring designs to elaborate geometric patterns (Figures 2.15 and 2.16). Chinese bronze mirrors are usually found fragmented and the context of these finds suggests the mirrors have been intentionally, probably ritually, broken before placement in the tombs (Miniyaev and Sakharovskaya 2007a). In contrast, the few imitation Chinese mirrors of central Asian style found in Xiongnu tombs were found intact and wrapped inside textile bags (Miller et al. 2006). These mirrors probably served a more functional purpose than the fragmented Chinese bronze mirrors.

Figure 2.15. Chinese bronze mirrors from Xiongnu burials. Gol Mod (left) and Tamiriin Ulaan Khöshöö (right). National Museum of Mongolia (Eregzen 2011:147, 149).

Figure 2.16. Bronze mirrors of central Asian manufacture. Burkhan Tolgoi (left) and Delgerkhaan Uul (right). National Museum of Mongolia (Eregzen 2011:146).

Animal sacrifice was not only an annual tradition, but was a key component of Xiongnu elite funerary rituals. These offerings consist of predominantly domesticated animals – sheep or goats, horses, cattle, and dogs. The head, hooves, and lower limbs are the animal portions most commonly interred with the deceased. Skulls of horses and sheep were discovered in an elite tomb at Takhilt, placed in a niche to the north of the coffin (Miller et al. 2008:30-31). This seems to be a tradition that developed from earlier nomadic cultures, as elaborate horse burials are also found in the Pazyryk cemetery, dating to around the 5th century BC (Rudenko 1970). The significance of the horse in the daily lives of the Xiongnu nomads carried over into their ritual and funerary practices.

Some elite tombs contain luxury items of gold, lacquer, and silk (for example, see Miller et al. 2008, Polos’mak et al. 2008). Many interred individuals were buried wearing belts composed of metal plates, hung with tools, weapons, and other accessories. At Takhilt cemetery, one grave contained metal tools, sheep astragali, and a long handled spoon with a small bowl, presumably hung from a belt (Jones and Joseph 2008:38-39).

2.4.4.4. Settlements and Internal Trade

There is archaeological evidence of Xiongnu structures and agricultural production (Figure 2.17). At the site of Tamir in the Tamir river valley in Arkhangai province, Mongolia, packed earth enclosures were excavated in 2005 (Purcell and Spurr 2006). Agriculture was also taking place on the steppe in some areas. During excavations at Ivolga, the remains of ploughshares and permanent settlement structures were discovered (Davydova 1995; Honeychurch 2006). These settlements may not have been occupied by ethnically Xiongnu people, but their presence on the steppe support the theory that the Xiongnu had control over groups practicing agriculture or had access to their agricultural products.

There is also evidence that limited trade was taking place within the Xiongnu Empire. Xiongnu pottery from the sites of Derstuy, Dureny I, Dureny II, Ivolga, and Tzaram near Lake Baikal in southern Siberia, and the site of Justyd in the Altai Mountains were analyzed by energy dispersive X-ray fluorescence (EDXRF) to determine the regional sources of the clay used in pottery production (Hall and Minyaev 2002:142). The pottery was of two different types; a grey/grey-brown type of fairly standard composition, unslipped with incised decoration, and a coarse reddish earthenware type that was unslipped and undecorated.

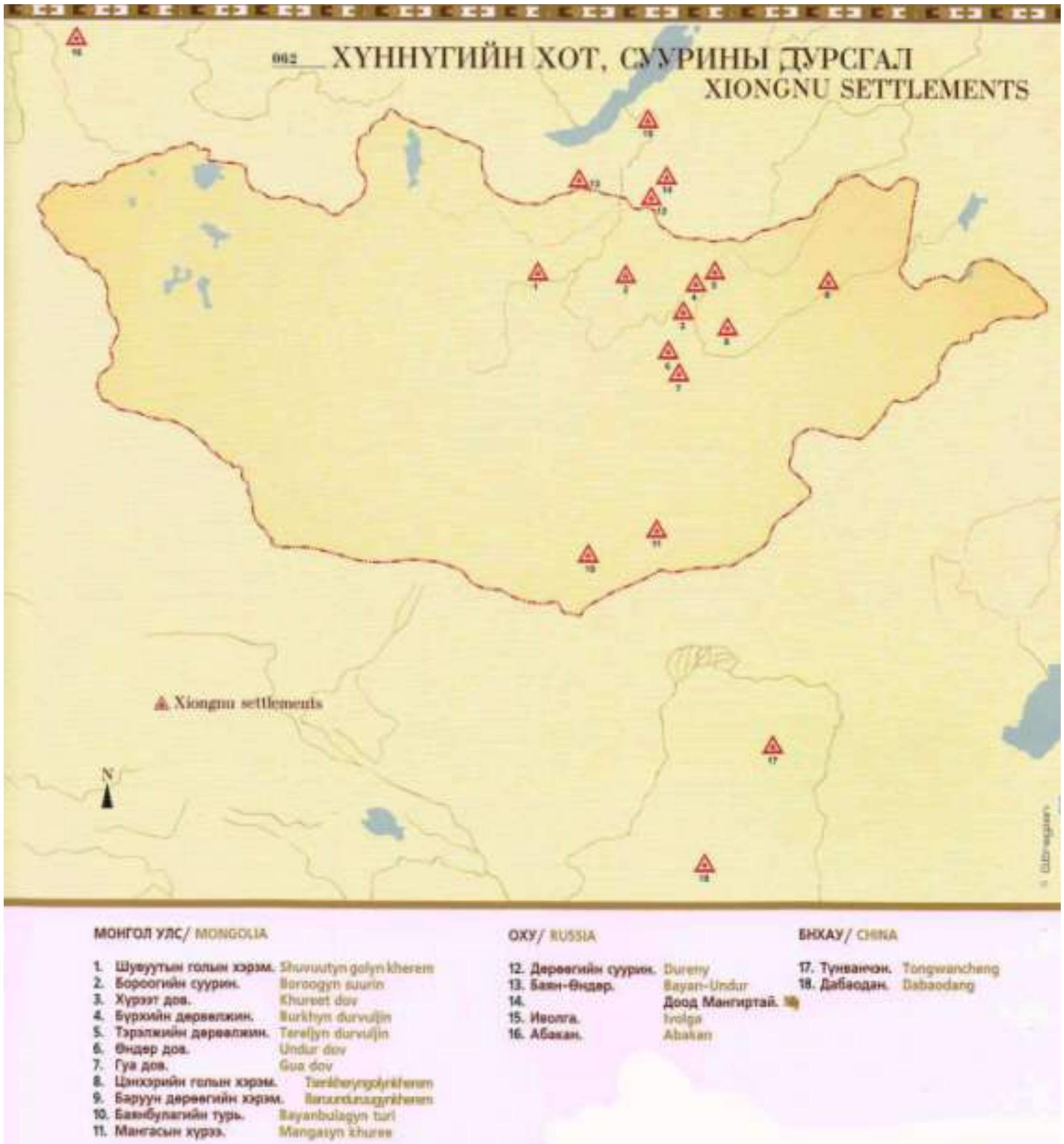


Figure 2.17. Map of Xiongnu settlement sites (National Museum of Mongolia Eregzen 2011:75).

The pottery seems to have originated from three different clay sources, two in the Trans-Baikal region, and one in the Altai region. However, the distribution of the pottery at the sites suggests there was limited movement of pottery between these areas. The pottery itself probably had no intrinsic value, but it could have been used to transport goods (such as grain) to different areas, or had been transported with people as they moved to different areas during their seasonal migration. The evidence for agricultural activity at Ivolga seems to support the hypothesis that grain produced at the site was redistributed to other areas in ceramic containers.

2.5. Conclusion

Previous historical and archaeological research sheds light on many aspects of Xiongnu society. How luxury items received from China or Central Asian states were distributed among the Xiongnu population, the impact of the imperial hierarchy on the lives of common tribespeople, whether the formal relationship between the Xiongnu and China significantly affected dietary composition, and which segments of the population were heavily involved in warfare or herding activities are some of the questions that the present research will investigate. These research questions will be discussed in the following chapter.

Chapter 3: Models of Nomadic Empire Formation and Research Hypotheses

3.1. Introduction

Within the community of Xiongnu scholars there is a lively debate about how and why a small group of nomads on the Mongolian steppe created an empire. As the first and most stable nomadic empire, creating models to explain the development of the Xiongnu Empire and its impact on the daily lives of members helps us understand the patterns of nomadic power throughout history (Honeychurch and Amartuvshin 2005:255).

Theories of the development of the Xiongnu Empire have been largely based on 20th century ethnography and historical accounts of pastoral nomadic societies (Honeychurch 2013). Most models of Xiongnu empire formation depend on the idea that the nomadic state emerged in tandem with the economic and political development of the Chinese empire to the south. The unsuitability of the steppe for large-scale production of agricultural goods and the unsuitability of the nomadic lifestyle to the production of manufactured goods made it necessary to acquire these commodities from China.

3.2. Definitions of Empire

In order to discuss theories regarding the emergence of nomadic empires, it is helpful to first describe the characteristics of traditional imperial states. Although scholars may have differing views on specific features, broad characteristics of ancient empires are generally accepted. Traditional or primary empires are defined as sovereign states that encompass a heterogeneous population and landscape (Sinopoli 1994 and 1995). In addition, these states usually maintain a standing army. They tend to have an expansionist policy and maintain control over large areas through military force. Empires generally have a capital that serves as the base of operations for authority figures. These capitals often incorporate monumental architecture as a means of displaying the power of the ruling class to the rest of the population (Sinopoli 1994).

One of the primary goals of an empire is to exploit resources from its various regions, including crops, labor, natural resources, and luxury items (Hirth 1996, Sinopoli 1995). In order to facilitate the collection of these resources, empires often invest in infrastructure such as roads and communication systems. Although many features of traditional empires do not apply to the Xiongnu, an overview of the general characteristics of primary empires provides a starting point from which to consider nomadic imperial states.

3.3. Early Models of Nomad-Chinese Frontier Interactions

Many studies of the Xiongnu (Barfield 1981, 2001; Di Cosmo 1999) have focused on theories about how nomadic empires developed, or have looked at the Xiongnu Empire as a model for later nomadic empires in Mongolia, such as the Uighurs and Mongols.

Owen Lattimore's *Inner Asian Frontiers of China* (1940) was the first work to recognize that an understanding of Inner Asia hinged on the transitional "frontier" zone between nomadic and sedentary cultures. Lattimore's interpretation of steppe societies incorporates the environmental characteristics where these societies develop and how they attempt to control their environment through their economic choices. Lattimore's work is the basis for much subsequent scholarship on Xiongnu-Han relations.

Yü Ying-shih's *Trade and Expansion in Han China* (1967) is the first in depth work that attempts to synthesize the literature and archaeological research focusing on the economic relations between the Han dynasty and its nomadic neighbors. The book focuses on the policies of Sino-nomadic trade and the tributary system (*heqin* policy), but also discusses commercial trade along the frontier. Border markets or *hushi* (胡市) established between the "barbarian" nomads and frontier populations and illicit trade across the border were important points of contact and exchange between the Xiongnu and Han people. Yü views trade as intertwined with politics, and the Han court accepted trade as a less costly alternative to warfare with the Xiongnu.

In *The Perilous Frontier* (1989), Thomas Barfield describes the steppe nomads as the only group that had been in contact with China for over 2,000 years without being incorporated into Chinese society or adopting Chinese customs. Barfield acknowledges that China and the nomadic tribes were in constant contact along the frontier and must have had considerable influence on one another. Establishing frontier markets was important to the Xiongnu people. The *heqin* policy established during the Xiongnu Empire supplied Chinese goods to the *chanyu*, who distributed them to the elites, but did not provide enough for the entire Xiongnu population. Once the *chanyu* had established the peace treaty, it was necessary to press the Han to set up border markets so the rest of the nomadic population could exchange pastoral goods with agricultural communities.

3.4. Shadow Empires

One widely-held model ties the emergence of steppe polities to the establishment of a strong, centralized, and stable Chinese state (Barfield 2001; Kradin 2002). This model suggests that the supra-tribal organization of steppe groups is a mechanism to obtain agricultural and manufactured goods from China that the low productivity and lack of diversity of a pastoral economy are unable to provide (Kradin 2002:380), and would be incapable of existing without a strong centralized state to exploit.

The unified Xiongnu Empire only emerges after the Chinese empire becomes stable under the Han Dynasty (Barfield 2001:10). Under the Han Dynasty, border trade was often restricted as a means of controlling resources and in response, steppe groups organized spatially extensive, weakly integrated confederations to facilitate external interactions. Internally, the Xiongnu remained loosely organized and maintained previous tribal hierarchies at the local level (Kradin 2002:374).

The “shadow empire” model (Barfield 2001) links the rise of the Xiongnu Empire to the development of a strong, unified Chinese state. The emergence and stability of the Xiongnu Empire was directly related to that of the Chinese empire. In this model, the Xiongnu operate as a shadow empire, with the political and military organization of a primary empire, but lacking key internal characteristics that would allow them to function at an imperial level independent of a strong agricultural state, like China.

Barfield describes the Xiongnu as a predatory empire, whose stability relied on its success in extorting goods from China. He argues that the Xiongnu Empire was politically organized specifically to exploit Chinese resources. There is no evidence, either historical or archaeological, that the Xiongnu ever sought to conquer China or even to occupy its agricultural lands. Barfield contends that the pastoral economy of the nomadic tribes did not have the diversity to legitimize the power of the *chanyu*, but the influx of agricultural and manufactured goods from China obtained through the Xiongnu imperial structure provided the necessary resources to justify an imperial structure and leader. Barfield lists five internal characteristics of primary empires (Barfield 2001:29-32):

1. Empires are organized to exploit diversity, whether economic, political, religious, or ethnic.
2. Empires establish transportation systems designed to serve the imperial center militarily and economically.
3. Empires have sophisticated communication systems that allow them to administer all subject areas directly from the imperial center.
4. Empires proclaim a monopoly of force within the territories they control and project their military force outward.
5. Empires have some form of "imperial project" that imposed a sense of unity throughout the system.

The Xiongnu Empire does not exhibit all of the characteristics of primary empires that Barfield describes, but recent research indicates that they were not as dependent on China as the “shadow empire” theory suggests.

Alternate Models of Nomadic State Formation

Di Cosmo (2002) proposes an alternate model of nomadic empire formation that downplays the role of the Chinese state in the emergence of the nomadic state. The Xiongnu conquered neighboring nomadic tribes and received tribute from them, in addition to the tribute received from China through the *heqin* agreement. Some of these neighboring tribes were practicing agriculture and were an important source of cereal products. Nomadic societies regularly incorporate components of agricultural or sedentary population within their society and for the Xiongnu these segments of society provided a source of agricultural products independent of their relationship with China (Di Cosmo 2002:197-198). Tribute goods from China may have been more important as a source of luxury goods or status items for Xiongnu elites than as a source of agricultural products.

The *chanyu* was the sole intermediary between the Han court and the nomadic tribal leaders. The amount of tribute the Xiongnu received through the *heqin* treaty is documented in Chinese texts. The annual allotment of grain from the Han would have fed about 700 people, as a supplement to a diet based on animal products. This would have been insufficient to support the population of the entire Xiongnu Empire. The grain, silks, and other luxury items received through the *heqin* agreement were most likely used by the *chanyu* for his personal use and for distribution to elites and allies to reward their loyalty and maintain prestige (Di Cosmo 1999). China could not have been the sole source of agricultural products for the entire population of the Xiongnu Empire.

DiCosmo identifies at least three spheres of political activity in play during the formation of nomadic states: among nomadic peoples, between nomadic peoples and major sedentary powers, and between nomadic peoples and minor independent sedentary polities (Di Cosmo 1999:13). He also emphasizes the role of internal actions and agency among the steppe tribes themselves in the formation of the Xiongnu Empire. Steppe groups have the economic diversity to be self-sufficient, but do not possess the resources to sustain a large-scale political organization without external income.

Key factors that contribute to the rise of steppe polities include regional social disruption created by internal or external events, consolidation of military power around a charismatic leader, establishment of an elite hierarchy, rapid military expansion, and political financing through tribute, taxation, and trade (Di Cosmo 2002). In this model, factors such as regional social disruption, consolidation of power around a charismatic leader, and mobilization of political finances are emphasized (Di Cosmo 2006).

3.6. Research Questions and Hypotheses

The research hypotheses developed for this study were designed to independently test the tenets of these various models of nomadic empire formation. Some of the questions this dissertation will address include:

1) How does the creation of the nomadic Xiongnu Empire affect the overall health of the people under its control? Is there any benefit to one's physical quality of life by participating in or forming the Xiongnu nomadic empire? Does health improve for individuals during the Xiongnu period when compared to their Bronze Age predecessors?

   For the purposes of this research, I define health in terms of the incidence of disease, dental health, level of nutritional stress, and trauma. Xiongnu populations will be compared to Bronze Age individuals from the Mongolian steppe to determine if health status changes across these time periods.

   If the formation of the Xiongnu Empire secured access to previously scarce foodstuffs and reduced the necessity of violent interactions between the Xiongnu and the Han Empire or between the Xiongnu and other nomadic tribes, I would expect to see this reflected in the health of the Xiongnu people. Differences in the rates of trauma, dental disease, and other stress indicators should reflect these changes.

2) Was health affected differently in certain segments of the population? Are there significant discrepancies between the health of individuals in the core area of Xiongnu power in central Mongolia and those living in the western or eastern peripheries?

   I hypothesize that health of individuals in central Mongolia should differ more markedly from their Bronze Age predecessors than those in the western or eastern regions of the Xiongnu Empire. If the Xiongnu elites in central Mongolia are the ones benefitting from the secure and peaceful access to Chinese goods, their health should be affected the most by the presence of the Xiongnu imperial system.

3) Does the amount of grain in the diet increase after the transition to the Xiongnu Empire? Is dietary composition consistent among members of Xiongnu society in different regions?

   Increased amounts of grain in the diet should be reflected by higher rates of dental caries and lower rates of degenerative changes in the temporo-mandibular joint. The rates of these indicators will be compared between individuals from different regions of the Xiongnu Empire, individuals from the Bronze Age period in Mongolia, and individuals living within the Han Empire.

4) Do the Xiongnu nomads exhibit better overall health than their sedentary, agricultural neighbors within the Chinese Empire?

   If the Xiongnu are able to increase the amount of Chinese agricultural goods in their diet as a result of tribute payments and border trade, the diets of these two groups should be more similar to one another than either one would be to the Bronze Age nomadic diet. I would expect this similarity in diet to be reflected in similar rates of antemortem tooth loss, dental caries, enamel hypoplasias, and degenerative changes in the temporo-mandibular joint in the Xiongnu and Han populations. However the different activities associated with nomadic pastoralism and agriculturalism should result in different patterns of degenerative joint disease between the two groups.

5) Does raiding- or warfare-related (violent) trauma among Xiongnu people decrease with the implementation of the *heqin* treaty between the Xiongnu and Han Empires?

    If the peaceful transfer of goods between the Han and Xiongnu Empires through the *heqin* treaty was enough to satisfy the Xiongnu desire for Chinese goods, I would expect the incidence of fracture and sharp force trauma to decrease in the Xiongnu, as compared to the Bronze Age sample.

    In addition, if Chinese goods are being distributed to Xiongnu elites and remaining in the core area of Xiongnu control (central Mongolia), I would expect that rates of trauma in eastern and western Mongolia would be similar to rates in the Bronze Age populations.

6) Does the structure and distribution of the population change during the Xiongnu period and if so, in what ways?

Expanding the area under Xiongnu control and enforcing the Xiongnu supra-tribal structure most likely involved the voluntary or involuntary movement of people. Individuals or groups of people from the Xiongnu lineage may have been relocated to new areas to act as representatives of the *chanyu*. Groups that were conquered and brought under Xiongnu control may have been displaced from the areas that they inhabited during the Bronze Age. Biological distance analysis will provide a way to look at patterns in redistribution and movement of the population.

3.7. Conclusion

Bioarchaeolgical analysis of Xiongnu skeletal material can contribute greatly to the discussion of nomadic empire formation. In addition to archaeological material, skeletal remains are a way to look beyond the organization of the system as a whole as described in texts and begin to understand the daily experiences of the people who make up and live within this society.

The results of this research will contribute new approaches to ongoing debates about the impact of the Xiongnu Empire on the quality of life of its population, the factors and conditions under which nomadic empires emerge, the dynamic relationship between China and steppe polities, and the cycles of power that occurred in the Mongolian steppe throughout history. This dissertation will also contribute to the larger field of empire studies by enabling cross-cultural comparisons between the Xiongnu and other empires across space and time, identifying similarities among them, as well as features unique to the Xiongnu Empire.

Chapter 4. Bioarchaeological Models

4.1. Introduction

Bioarchaeological and biological distance analysis methods were used in this study to address the research question and test the hypotheses described in Chapter 3. This chapter will discuss the bioarchaeological models used to determine the health and migration impacts upon nomadic people as a result of the creation of the Xiongnu Empire.

4.2. The Bioarchaeological Approach

Over the past several decades, bioarchaeological studies have shifted from a focus on unusual or interesting individual cases to research investigating health at the population level (Bush and Zvelebil 1991). Data from skeletal material, including patterns of skeletal lesions and cranial measurements, can be useful in identifying variations in disease, diet, physiological stress, violence, and population structure associated with socio-cultural practices. Bioarchaeological studies can also shed light on the nature interactions among different groups, such as Eng's bioarchaeolgical study of frontier interactions between Mongolian nomads and Chinese agriculturalists (2007).

4.2.1. The Osteological Paradox

When making inferences from skeletal data certain biases must be considered. In 1992, Wood et al. described the "osteological paradox." They argue that skeletal samples are by their very nature a non-representative sample of the living population they came from (Wood et al. 1992:344). Because skeletal data are solely comprised of individuals who died from a certain disease at a given age, the frequency of skeletal lesions observed in a sample does not directly reflect the prevalence of that disease in the living population. The presence of a lesion cannot clearly differentiate whether a pathological condition persisted until the individual died, or if the individual survived the disease and died at a later time (Wood et al. 1992:365). Skeletal markers of chronic illnesses may be only weakly related to cause of death (Cohen et al. 1994:631).

Conversely, the absence of skeletal lesions can not necessarily be interpreted as the absence of disease. The individual may have succumbed to a disease before any skeletal involvement occurred (Wood et al. 1992:365). To minimize the impact of biases inherent in skeletal data, multiple lines of evidence and multiple indicators of health can help clarify the relationship between skeletal lesions and health status (Cohen 1992:358-359; Dewitte and Stojanowski 2015; Goodman 1993; Wright and Yoder 2003:56-57).

4.2.2. Agriculturalism

The transition from foraging to farming had significant impacts on social organization, settlement patterns, population density, and social stratification (Cohen and Armelagos 1984; Hayden 1995; Larsen 1995; Price and Gebauer 1995:6). These changes are often associated with many negative health impacts, including a reduced age at death and an increase in pathological skeletal lesions. As dependence on domesticated cereals increased dietary diversity decreased, indicators of dental disease and malnourishment also increased. Excess production of foodstuffs allowed for social stratification and craft specialization which led to variations in health status among different segments of agricultural societies.

4.2.3. Nomadic Pastoralism

Nomadic pastoralism is a mode of subsistence that is characterized by an economic reliance on herd animals. This requires the population to be mobile in order to take maximum advantage of pasture resources (Barfield 1993). There are two main types of nomadic pastoralism. Transhumance involves a core sedentary population, usually participating in crop cultivation, while a segment of the population travels seasonally with the herds and returns to the sedentary settlement. Nomadic pastoralism involves the movement of the entire community with the herd to new pasture land (Barfield 1993). Nomadic pastoral societies generally have less sexual division of labor than agricultural societies. The periodic movement, lower population density, and more diverse animal-based diet tends to result in lower rates of dental caries, nutritional deficiencies and parasite and infectious disease loads than agricultural populations.

4.3. Bioarchaeological Correlates of Dietary Composition

The food consumed by an individual during their life leaves direct skeletal and dental markers that can be used to reconstruct dietary composition and food preparation methods. In this section, I will discuss some of these standard markers and what they can tell us about the dietary habits of a population.

4.3.1. Dental Disease

Dental pathologies are an important indicator of diet and overall health. The presence of carious lesions, dental calculus, and occlusal wear can provide information about the composition and quality of an individual's diet (Dobney and Brothwell 1986, Hillson 2000). For instance, evidence of periodontitis and abscesses suggest dietary or systemic stress (Clarke and Hirsch 1991).

Dental caries, the demineralization of tooth enamel creating a lesion on the tooth, can be caused by a diet high in carbohydrates, such as the diet of most agricultural societies (Powell 1985; Rose et al. 1984; Turner 1979). Other factors that can lead to dental caries include inadequate oral hygiene, defects that cause a weakening of tooth enamel (like enamel hypoplasias), food preparation practices, and using teeth as tools (Larsen et al. 1991:179).

Tooth abscesses occur when the bacteria that cause dental caries (*Streptococcus mutans* or *Lactobacillus*) penetrate through the gum tissue into the alveolar bone, creating an infection. In some cases the pressure from the infection becomes so great that it breaks through the alveolar bone, creating a channel through which the infection can drain (Clarke and Hirsch 1991).

Infections of alveolar bone are often the cause of ante-mortem tooth loss (AMTL). The destruction of the alveolar bone holding the tooth in place leads to the loss of that tooth (Hillson 1996). Other causes of AMTL are trauma, dietary deficiencies such as scurvy, and intentional tooth extraction.

Dental calculus is caused by the mineralization of dental plaque on the teeth. Protein deposits harden on tooth enamel caused by the action of bacteria and saliva. The presence of dental calculus indicates a high level of protein in the diet (Hillson 1979, Dobney and Brothwell 1986).

4.3.2. TMJ Disease

Osteoarthritic changes of the temporo-mandibular joint (TMJ) can indicate changes in dietary composition. Masticatory force loads on the TMJ, so diets that include a higher amount of soft foods, like processed grains, will put less strain on the TMJ, as well as less occlusal wear and tooth attrition (Hodges 1991; Sheridan et al. 1991). The rate of degenerative changes to the TMJ is typically lower in agricultural populations.

4.3.3. Isotopic Profiles

Analysis of stable isotopes, particularly nitrogen and carbon, in bone collagen and bone and tooth apatite has the potential to reveal detailed information about the relative composition of various dietary sources (Katzenberg 2008; Tykot 2004). Differential fractionation of atmospheric carbon dioxide and nitrogen between certain plant groups results in different isotopic ratios of $^{12}C/^{13}C$ and $^{15}N/^{14}N$ (the two stable isotopes of carbon and nitrogen, respectively) that are in turn reflected in the isotopic ratios of human bone. The results of isotopic profile analyses can help determine the relative importance of different grains (rice, wheat, millet, sorghum) and protein sources (marine or terrestrial) in the diet (King and Norr 2006).

4.4. Bioarchaeological Correlates of Health Status

Differences in diet and living conditions can have significant impacts on health. Non-specific stress markers, such as reduced stature, enamel hypoplasia, porotic hyperostosis, and osteoperiostitis, are indicative of periods of physiological stress, especially during development.

4.4.1. Stature

Stature is a good indicator of overall population health. When individuals experiences stress (environmental, dietary, or disease-related), they are less likely to reach their genetically-determined stature potential (Steckel 1995). Malnourishment and systemic disease during development can lead to a lower realized adult stature (Huss-Ashmore et al. 1982:403). Comparing stature for different populations can indicate whether one group was under relatively higher stress.

4.4.2. Non-specific Stress Markers

Many diseases do not leave skeletal lesions, but studying bone abnormalities can still provide information about general health status, estimates of community health, and disease history (Buikstra and Ubelaker 1994:107). Non-specific pathological markers, such as dental enamel hypoplasia (Goodman and Rose 1990), porotic hyperostosis (Kent 1986; Lallo et al. 1977; Walker et al. 2009), and Harris lines (Garn et al. 1968) can be used to make hypotheses about the relative health of a population. On the other hand, differential diagnoses can often be made of specific diseases like tuberculosis (Roberts and Buikstra 2003), scurvy (Brickley and Ives 2008:56-61), rickets (Brickley and Ives 2008:51-69, 94-133), and osteoporosis (Brickley and Agarwal 2003; Stini 1995).

Brucellosis is one infectious disease that could potentially be a significant factor in the health of nomadic pastoralist populations. Brucellosis is a zoonotic disease caused by bacteria of the genus *Brucella* (Brothwell 1991:21). It is passed among animals and can be transmitted to humans who come in contact with infected animals and animal products. The various strains of these bacteria commonly affect goats, sheep, and horses (CDC 2007; Denny 1973), all animals with which individuals within the Xiongnu Empire would have had close contact. Acute symptoms include fever, headaches, back pain, and physical weakness. Chronic infection can cause long term symptoms including joint pain and fatigue (CDC 2007).

This disease is a concern for modern pastoral populations. Human brucellosis infection are common in Mongolia today (Ebright et al. 2003:1511) and a few instances have been identified archaeologically (Capasso 1999; Mutolo et al. 2012). Recently, brucellosis diagnosed in archaeological samples though observation of circular lytic lesions of thoracic and lumbar vertebrae was confirmed through DNA testing in two individuals from a 10-13th century cemetery in Butrint, Albania (Mutolo et al. 2012). The lesions are similar to those observed in cases of tuberculosis (Cordero and Sanchez 1991; Mutolo et al. 2012:255), so a differential diagnosis of brucellosis is often difficult. The confirmation of a brucellosis diagnosis through DNA analysis helps to identify the specific changes in skeletal morphology which leads to more accurate diagnoses of this disease in archaeological skeletal remains.

4.4.2.1. Enamel Hypoplasia

Enamel hypoplasia can occur when an individual experiences dietary stress during tooth formation and is characterized by variations in the thickness of enamel deposited on the tooth crown. They can appear as grooves, pits, or areas of missing enamel on the teeth (Buikstra and Ubelaker 1994:56-58). The etiology of enamel hypoplasia is poorly understood, but the presence of these lesions can indicate periods of physiological stress during tooth development (Goodman and Rose 1990, 1991). The presence of these lesions could be indirectly related to dietary intake, as nutritional deficiencies are one possible factor in their development (Steckel 2005).

4.4.2.2. Porotic Hyperostosis

Porotic hyperostosis (PH) refers to a variety of skeletal lesions of the cranial vault and the roof of the eye orbitals (also known as cribra orbitalia). These lesions are the result of expansion of the diploe of the cranial vault bones in response to diminished red blood cell activity (Stuart-Macadam 1989). There are many factors that contribute to the presence of PH lesions, including iron deficiency anemia from either dietary malnutrition or disease (Goodman and Martin 2002; Huss-Ashmore et al. 1982). Recent studies suggest there are multiple factors that contribute to the presence of this disease (Holland and O’Brien 1997; Walker 2009).

4.4.2.3. Osteoperiostitis

Chronic infectious disease can result in a skeletal response. Osteoperiostitis is the deposition of bone on the outer surface in response to infection (Ortner 2003). These lesions can result from localized or general diseases, and are indicative of increased stress in a population (Larsen 1997).

4.5. Bioarchaeological Correlates of Interpersonal Violence and Activities

When individuals engage in activities regularly over long periods of time, skeletal markers develop as a result of those repeated anatomical movements. Activities that result in interpersonal violence can also leave evidence of these conflicts in the form of trauma. This section will describe some of these indicators of violent or habitual activities.

4.5.1. Trauma

Trauma occurs when the body sustains physical injury caused by an external force. Trauma can be the result of blunt or sharp forces and can be caused by many things including accidental injury, interpersonal violence, and intentional medical intervention. The incidence of trauma within a population can indicate a physically hazardous lifestyle, occupational hazards, periods of interpersonal violence, or the practice of medical procedures (Lovell 1997).

4.5.2. Degenerative Joint Disease

Degenerative joint disease (DJD) affects the major joints of the body, and is widely considered to be the result of movements repeated long-term while performing habitual activities (Larsen 1997; Waldron 1997). DJD can be observed macroscopically as the presence of osteophyte formation, eburnation, and/or porosity of articular surfaces. The pattern of joints affected by DJD can be used to determine variations in the types of physical activities different populations regularly engage in (Larsen 1997; Lieverse et al. 2007; Stirland 1991).

4.6. Biological Distance Analysis

4.6.1. Introduction

Biological distance refers to assessing genetic similarity between populations based on the analysis of phenotypic traits that have a genetic basis (Buikstra et al. 1990; Stojanowski and Schillaci 2006). All biological distance studies assume that the measurements used in the analysis actually reflect genetic relationships between individuals (Stojanowski and Schillaci 2006). Genetic heritability (h^2) of traits is estimated by studying skeletal samples of individuals of known relatedness (Carson 2006; Martínez-Abadías et al. 2009). Estimates of h^2 range from 0, no genetic heritability to 1, completely genetically determined. There are no statistically significant differences in heritability from cranial base, vault, or facial dimensions. For the purposes of this study, h^2=0.55 is used as the average heritability of cranial traits (Carson 2006:170).

Phenotypic variation is commonly understood to derive from a combination of genetic and environmental factors (Konigsberg 2000). Represented by the variance component factor: $V_P = V_G + V_E$. V_P equals the total phenotypic variation, V_G equals the genetic variance, and V_E represents the environmental variance (Konigsberg 2000). F_{st} is a measure of genetic structure developed by Sewall Wright (1969, 1978). It represents the proportion of the total genetic variance contained in a subpopulation (the S subscript) relative to the total genetic variance (the T subscript). Values can range from 0 to 1. A high F_{st} value implies a considerable degree of genetic differentiation among populations.

In this study, I am utilizing the R Matrix method to analyze biological distance among populations. This is a model-bound approach developed by Relethford and Blangero (1990) to calculate levels of gene flow, genetic distance, and intra-group variation. R Matrix analyses of craniometric data will provide some insight into the patterns of phenotypic variation resulting from the displacement of populations under Xiongnu imperial rule. Areas where individuals were displaced as a result of Xiongnu imperial expansion or where individuals of the Xiongnu elite lineage were relocated to rule remote populations may have cemetery contexts that display greater than expected heterogeneity. In areas that did not experience displacement of local populations under Xiongnu rule, or in areas where the Xiongnu lineage lived during the Bronze Age and retained as their homeland might display more homogeneity among members of its cemetery populations. In these areas we would also expect similarities in the phenotypic characteristics of individuals in Bronze Age and Xiongnu period cemeteries. Biological distance analysis can provide an approach for identifying patterns in cemetery composition that improves our understanding of the complex ways in which the structure of populations under Xiongnu influence were affected by imperial expansion and rule.

4.6.2. Metric Data

Metric analyses of biological distance often use standardized linear osteometric measurements (Buikstra and Ubelaker 1994). Cranial measurements taken from standardized landmarks are most commonly used for biological distance studies, as these dimensions are less influenced by environmental factors than post-cranial metrics (Stojanowski and Schillaci 2006).

4.6.3. Non-metric Data

Non-metric data sets can also be used in biological distance analyses. These traits cannot be measured in a quantitative fashion, but can be observed as present or absent (Buikstra and Ubelaker 1994, Hauser and DeStefano 1989). Non-metric traits can be important when skeletal material is fragmented or damaged to such an extent that craniometric data cannot be recorded.

4.8. Conclusions

This chapter discusses the bioarchaeological models used in this study to analyze skeletal data and their correlation to socio-political factors to interpret the results. Human remains should be viewed and treated differently than any other type of archaeological material. The study of skeletal material requires respect for the individual whose remains are being analyzed, and consideration for the descendant populations that may be affected by the results of the research being conducted. The information that can be gained by studying human remains not only provides insight into the past but can also have political implications for modern populations. It is also crucial to conserve skeletal remains and to preserve any samples collected so that the results of any tests can be duplicated by future researchers. Ethical standards for bioarchaeological research have been discussed in great detail in several works (Alfonso and Powell 2007; Day 1990; Jones and Harris 1998) which were followed during the course of this study.

Chapter 5: Research Collections and Data Sample

5.1. Introduction

To investigate the research questions posed in this dissertation, I collected data from two institutions in East Asia. The national University of Mongolia (NUM) Department of Anthropology in Ulaanbaatar, Mongolia houses a skeletal collection of remains from over 900 individuals excavated from sites across Mongolia. These materials span the Neolithic through the Mongol period. The Research Center for Chinese Frontier Archaeology (RCCFA) at Jilin University in Changchun, People's Republic of China holds a skeletal collection of over 4,000 individuals. These remains have been excavated from archaeological sites across northern China from the Neolithic through the Iron Age periods.

The sample of materials I chose for this project includes individuals from the Bronze Age through the early Iron Age. I chose twenty-six cemetery sites in Mongolia and one site in China. These sites were selected because they represent sites from across Mongolia, with one site chosen to represent the sedentary agricultural population in China. Figure 5.1 and 5.2 show the geographic locations of the sampled sites within the study area. I focused on the most fully excavated sites available for analysis. Some material held in the collections of these institutions was not available for study because they are being analyzed for other research projects or are restricted for other reasons.

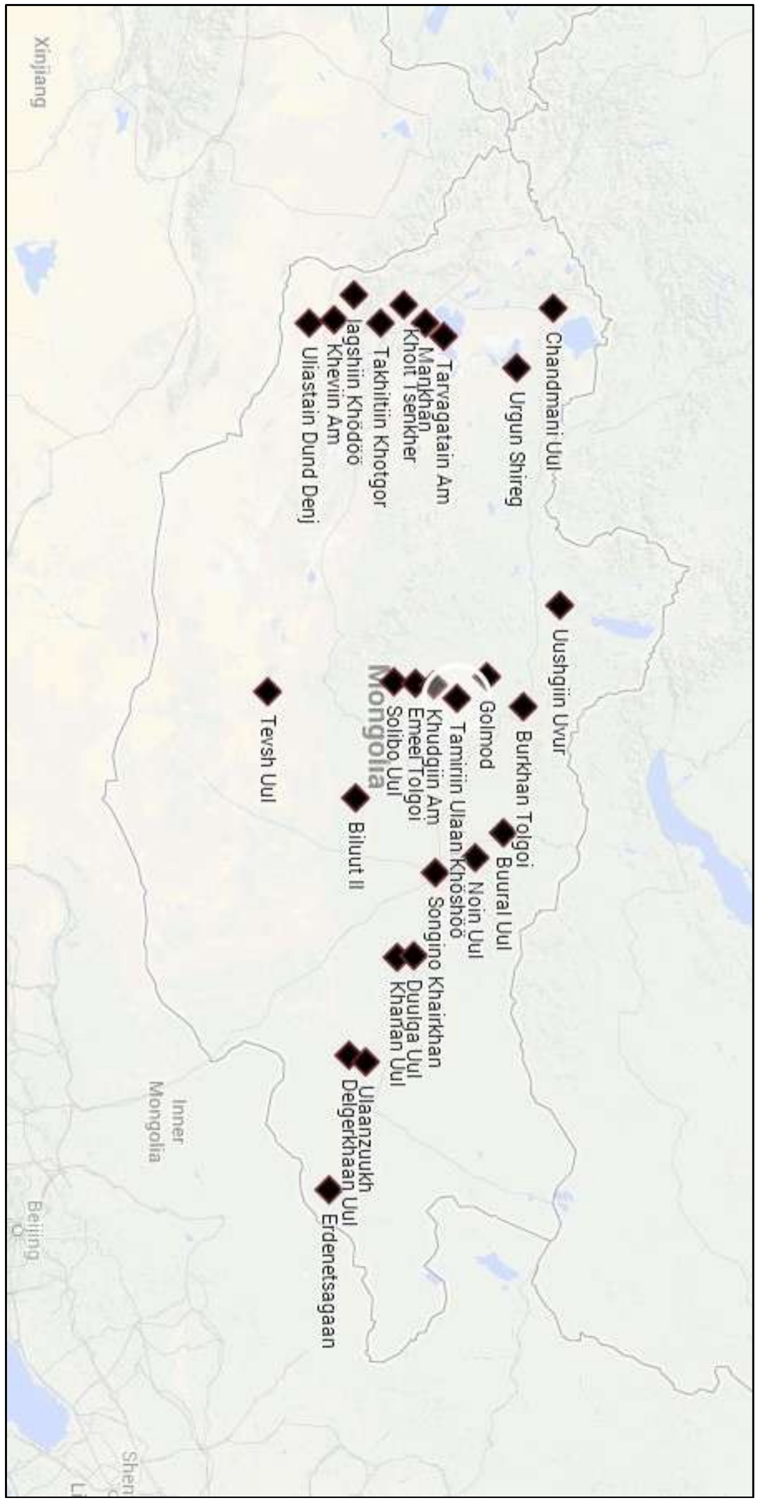


Figure 5.1. Location of Mongolian archaeological sites within study area (Google Maps 2015).

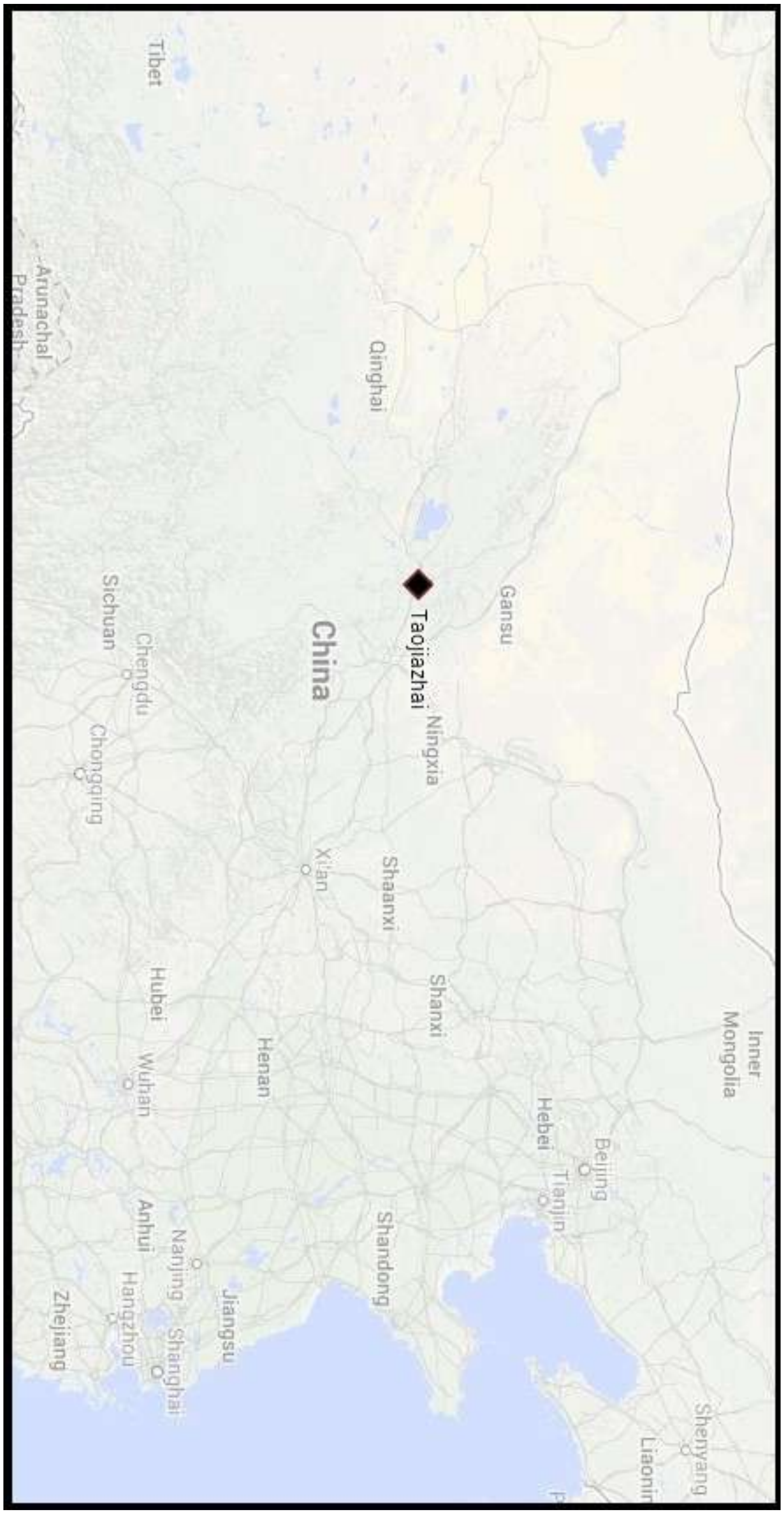


Figure 5.2. Location of Taojiazhai site within study area (Google Maps 2015).

This chapter will discuss the sampling strategy and the challenges presented while working with these collections. Next, a brief description of each site including the location, time period, and cultural context as available is provided. For several sites the excavation reports or other publications on the site background were not available. In these instances the information is limited to the notes in the collection catalogs. Geographic coordinates of site locations are also taken from catalog notes. The site name abbreviations are my own.

5.2. Sampling Strategy

I had 90 days to gather data at each institution. After consulting with the lab directors, looking at the collection catalogs, and thinking about how to address my research questions, the data sample was chosen to best utilize lab time and get the best representative sample of individuals for the research goals. This sample is not random; it represents sites across the geographic extent of Xiongnu control in Mongolia that have a significant proportion of excavated burials. I also included data from skeletal remains from one site in China, to represent the sedentary agricultural population within the Chinese empire during the Xiongnu period. I chose the sites to include in my sample based on the following criteria:

- The cemetery included individuals from the Bronze Age, Xiongnu period, or both. The site may also include individuals from other time periods (Neolithic, Mongol period, etc.), but I did not collect data from those individuals.

- The geographic distribution of sites represents the entire Xiongnu Empire. Xiongnu control spanned a large geographic area, but the strength of that control likely varied across the region. I chose sites from western, eastern, and central Mongolia to represent the extent of Xiongnu influence across the steppe and to explore varying levels of Xiongnu control and the impact of that variation on people in different areas.

A summary of the site names, locations, time periods, and number of individuals analyzed is shown in Table 5.1.

Table 5.1. Summary of site information.

Site	Territory	Region	Time Period	n
Chandmani Uul (CU)	Uvs	Western Mongolia	Bronze Age	12
Iagshiin Khödöö (IK)	Khovd	Western Mongolia	Bronze Age	3
Kheviin Am (KA)	Khovd	Western Mongolia	Bronze Age	4
Khoit Tsenkher (KT)	Khovd	Western Mongolia	Bronze Age	3
Ulaanzuukh	Sukhbaatar	Eastern Mongolia	Bronze Age	10
Uliastain Dund Denj	Khovd	Western Mongolia	Bronze Age	5
Urgun Shireg	Uvs	Western Mongolia	Bronze Age	2
Uushgiin Uvur	Khuvsgul	Western Mongolia	Bronze Age	5
Biluut II (BA)	Bayan Ulgii	Western Mongolia	Xiongnu	3
Burkhan Tolgoi (BT)	Bulgan	Central Mongolia	Xiongnu	5
Buural Uul (BU)	Selenge	Central Mongolia	Xiongnu	13
Delgerkhaan Uul (DKU)	Sukhbaatar	Eastern Mongolia	Xiongnu	3
Duulga Uul (DU)	Khentii	Eastern Mongolia	Xiongnu	7
Emeel Tolgoi (ET)	Arkhangai	Central Mongolia	Xiongnu	6
Erdenetsagaan (ES)	Sukhbaatar	Eastern Mongolia	Xiongnu	1
Golmod (GM)	Arkhangai	Central Mongolia	Xiongnu	1
Khanaan Uul (KU)	Khentii	Eastern Mongolia	Xiongnu	1
Khoit Tsenkher (KT)	Khovd	Western Mongolia	Xiongnu	2
Khudgiin Am (KGA)	Arkhangai	Central Mongolia	Xiongnu	2
Mankhan (MK)	Khovd	Western Mongolia	Xiongnu	2
Noin Uul (NU)	Tuv	Central Mongolia	Xiongnu	1
Solibo Uul (SU)	Arkhangai	Central Mongolia	Xiongnu	2
Songino Khairkhan (SK)	Tuv	Central Mongolia	Xiongnu	2
Takhiltiin Khotgor (TK)	Khovd	Western Mongolia	Xiongnu	4
Tamiriin Ulaan Khöshöö (TUK)	Arkhangai	Central Mongolia	Xiongnu	11
Tarvagatain Am	Khovd	Western Mongolia	Xiongnu	1
Tevsh Uul	Uvurkhangai	Central Mongolia	Xiongnu	7
Taojiazhai	Qinghai	Northwest China	Han Dynasty	231

5.3. Sampling Biases

Research based on data gathered from human remains includes some biases because of the nature of the material being studied. Any sample of human skeletal remains is by definition comprised of individuals who have died from natural, accidental, or violent causes. Cemetery populations are not inherently biased. Treatment and disposal of the dead however, is not uniform. The number of individuals interred in cemeteries attributed to the Bronze Age and Xiongnu period in Mongolia do not account for the entire population during those times. Methods of human disposal that leave little to no archaeological trace, such as sky burials or cremation, may account for this discrepancy.

Tomb burials may have been reserved for individuals of higher status, but may occasionally have included individuals of arguably the lowest status – sacrificial victims who were probably slaves or prisoners of war. My sample of individuals excavated from cemeteries is probably heavily skewed toward elite populations for the Bronze Age and Xiongnu period. However, as all of the sample is biased in this same manner it is still useful and accurate for comparative purposes. It will not, unfortunately, allow me to make any comparisons related to different social strata.

Differential preservation can also cause misrepresentation in a skeletal sample. Remains of infants, children, elderly individuals, and individuals with conditions that affect bone durability will be underrepresented in cemetery samples and if present, are more likely to be less complete and more damaged than more healthy or robust bone samples. Delicate bone elements within a given individual skeleton will also be less likely to survive post-depositional taphonomic processes intact. Again, this bias should be relatively consistent across samples from the different sites I have selected. I did gather data from incomplete or poorly preserved individuals from the sites I chose to the extent that I was able.

5.4. National University of Mongolia Collection

The collection of human skeletal remains at NUM contains approximately 900 individuals from over 110 sites across Mongolia. Cranial and postcranial remains were curated separately and housed in different locations. Cranial remains are stored in lab space within the Department of Anthropology. Each skull is individually boxed and labeled with the name and location of the site, time period, and catalog number for each individual. I was able to locate and analyze all individual crania from the sites I chose to include in this sample.

Several cemetery sites contained Bronze Age and Iron Age burials. These sites were included for their usefulness in identifying change over time at the same geographic location, especially changes in the ethnic groups inhabiting an area. Significant changes in the biological affinity of individuals at a site during different time periods may indicate relocation or redistribution of people between the Bronze Age and Xiongnu time periods.

The majority of the postcranial remains were stored off-site in a non-climate controlled environment. Postcranial remains were not boxed individually and were much more difficult to locate in storage than the cranial remains. In many cases, the postcranial remains corresponding to a cranium in the collection could not be located or had not been collected and retained. Preservation of cranial remains was generally better than that of the postcranial remains.

I was given a table in the lab to use for analysis of the remains. I had adequate space for examining and photographing remains. Lighting in the lab was adequate for analysis, but often made photography difficult.

5.4.1. Mongolian Bronze Age Sites

5.4.1.1. Chandmani Uul (CU)
Latitude and Longitude: 49° 57' 46.3" N 092° 03' 58.5" E

This cemetery site is located in the Chandman mountains in Uvs province, western Mongolia. It dates to the late Bronze Age (c. 700-300 BCE). The site was fully excavated between 1972 and 1974 by a joint Mongolian-Russian team (Tseveendorj 1980). One hundred and fourteen individuals were excavated from this site, however many of them are housed in the collections of the Mongolian Academy of Sciences Institute of Archaeology. Twelve individuals from this site in the NUM collection are included in this sample.

5.4.1.2. Iagshiin Khödöö (IK)
Latitude and Longitude: 46° 07' 29.4" N 091° 34' 32.5" E

This site is located in Khovd province, western Mongolia. Radiocarbon dates from human bone place this site in the middle Bronze Age, between 2500 and 2000 BCE (Kovalev and Erdenebaatar 2009: 153-154). I analyzed 3 individuals excavated from this site for the present study.

5.4.1.3. Kheviin Am (KA)
Latitude and Longitude: 46° 08' 68.5" N 091° 29' 62.5" E

The NUM collections catalog records state that Kheviin Am is located in Khovd province in western Mongolia. Radiocarbon dates from human bone samples place this site in the middle-to-late Bronze Age, approximately 2500 to 1700 BCE (Kovalev and Erdenebaatar 2009: 154). No additional publications or site reports were available.Four individuals from this site were analyzed for the present study.

5.4.1.4. Khoit Tsenkher (KT)
Latitude and Longitude: 47° 24' 19.4" N 092° 06' 01.0" E

No site reports or other publications were available on the excavations at Khoit Tsenkher. According to the NUM collections catalog records, this site is located in Khovd province, western Mongolia. The site contained burials dating to the Bronze Age and Xiongnu period, based on burial style. Three individuals from the Bronze Age and two individuals from the Xiongnu period are included in this sample.

5.4.1.5. Ulaanzuukh (UZ)
Latitude and Longitude: 46° 39' 05.7" N 111° 51' 41.0" E

This site is located in the Tuvshinshiree district of Sukhbaatar province in Eastern Mongolia. During survey conducted by the Department of Archaeology and Anthropology at the National University of Mongolia in 2009 and 2010, 64 rectangular graves and one figure grave were discovered. This site, dating to the early Bronze Age (1500-1000 BCE), contained burials displaying unusual features, including the tendency to bury the deceased in a prone position (Tumen et al. 2010, 2012). This is one of the type sites of what Honeychurch (2014: 124-125) calls the “Ulaanzuukh-Tevsh culture.” Ten individuals were analyzed from this site.

5.4.1.6. Uliastain Dund Denj (UDD)
Latitude and Longitude: 45° 23' 41.2" N 090° 48' 09.9" E

No site reports or other publications are available for this site. The NUM collections catalog records indicate that Uliastain Dund Denj is located in Khovd province, western Mongolia. It is classified as a Bronze Age site. I analyzed the remains of five individuals from this site.

5.4.1.7. Urgun Shireg (US)
Latitude and Longitude: 49° 36' 33.8" N 093° 52' 47.2" E

No site reports or publications on Urgun Shireg are available. According to the NUM collections catalog, this site is located in Uvs province, western Mongolia. Based on burial features and grave goods this site is classified as Bronze Age. Two individuals were excavated from this site and they are both included in my data sample.

5.4.1.8. Ushigiin Uvur (UU)
Latitude and Longitude: 49° 39' 16.2" N 099° 55' 39.0" E

Also known as Ulaan uushig, Uushigiin uvur in located southeast of Ulaan Uushig mountain in Khuvsgul province, western Mongolia. The site contains all of the features associated with the Mongolian Bronze Age cultural complex: deer stones, khirigsuur monuments with stone enclosures, and slab graves (Takahama et al. 2006).

This site was first examined in 1970 by V. V. Volkov and Novgorodova (Volkov 2002). Excavations by a joint team from Kanazawa University and the National University of Mongolia began in 1999 (Takahama et al. 2006). Five individuals from this site are included in this sample.

5.4.2. Xiongnu Sites

5.4.2.1. Biluut II (BL)

Latitude and Longitude: 48° 39' 14.82" N 88° 21' 37.08" E

Biluut 2 was excavated in 2011 and 2012 by a joint team from the National Museum of Mongolia and the Smithsonian Institute. The site is located in the hills near the Khoton Lake in the Tsengel district of Bayan Ulgii province in western Mongolia (Fitzhugh and Kortum 2013). There are many archaeological features near Biluut 2 including petroglyphs, deer stones, and burials from the Paleolithic through the Iron Age (Kortum 2014).

The three individuals analyzed are from a separate excavation project carried out by the NUM. The NUM catalog information classifies these burials as Xiongnu period, presumably based on burial architecture and style of grave goods. No additional information about the NUM excavation is available.

5.4.2.2. Burkhan Tolgoi (BT)

Latitude and Longitude: 46° 55' 21.4" N 105° 53' 50.0" E

Burkhan Tolgoi sits in the Egiin Gol valley in the Bulgan province, northern-central Mongolia. The site was in use between the 4^{th} and 2^{nd} centuries BCE (Torbat et al.

2003:136-137), although more recent radiocarbon dates place the time of use between the 1st century BCE and the 2nd century CE (Brosseder et al. 2011).

Excavations took place from 1997 to 2001 by a joint Mongolian-French team, the Mission archéologique française en Mongolie (Torbat et al. 2003). The burials are Xiongnu ring style tombs. Some of the tombs contained faunal remains, including domesticated sheep, goats, horses, and dogs, and wild deer. Remains of eight individuals were excavated from this site and five of these individuals are included in this sample.

5.4.2.3. Buural Uul (BU)
Latitude and Longitude: 49° 26' 09.7" N 106° 02' 00.8" E

Site reports or other publications about the Buural Uul excavations were unavailable. According to the NUM collection records, this site is located in the Selenge province in central Mongolia. Buural Uul cemetery contains burials from the Bronze Age, Xiongnu, and Mongol periods. Burials of each time period were presumably dated based on style of burial and grave goods. Thirteen Xiongnu-period individuals were analyzed from this site.

5.4.2.4. Delgerkhaan Uul (DKU)
Latitude and Longitude: 46° 05' 29.5" N 111° 47' 53.9" E

Delgerkhaan Uul is located in Sukhbaatar province, eastern Mongolia. A team from NUM conducted survey excavations at this site (Tumen et al. 2010, 2012). There are large Xiongnu period cemeteries and habitation areas at this site, but no evidence of any Bronze Age monuments or burials (Honeychurch 2014). Ten Xiongnu burials have been excavated at this site and three of these individuals are included in this sample.

5.4.2.5. Duulga Uul (DU)
Latitude and Longitude: 47° 19' 52.1" N 109° 43' 08.2" E

This site is located in Khentii province, eastern Mongolia. The burials date to the Xiongnu period, with no associated Bronze Age monumental or burial activity (Honeychurch 2014: 251). The remains of eleven individuals excavated from this site are held in the collection at NUM and seven of them have been included in this sample.

5.4.2.6. Emeel Tolgoi (ET)
Latitude and Longitude: 47° 47' 05.2" N 102° 17' 03.3" E

No site reports or other publications on the excavations at Emeel Tolgoi are available, but the NUM collection catalog records state that this site is located in Battsengel district in Arkhangai province, central Mongolia. This site is classified as Xiongnu period based on burial architecture and style of grave goods. Six individuals from this site are included in this sample.

5.4.2.7. Erdenetsagaan (ES)
Latitude and Longitude: 45° 54' 42.7" N 115° 22' 12.6" E

Excavation reports and other publications about Erdenetsagaan are unavailable. The NUM collection catalog records indicate that this site is located in Sukhbaatar province, eastern Mongolia. The burial dates to the Xiongnu period. One individual was excavated from this site and is included in this sample.

5.4.2.8. Gol Mod (GM)

Latitude and Longitude: 48° 51' 39.963" N 101° 46' 58.2132" E

This elite Xiongnu cemetery site is located in the foothills of the Khangai mountain range in Arkhangai province, central Mongolia. In addition to the Xiongnu burials, Bronze Age deer stone and khirigsuur monuments and Turkic period features are located in the area. The first excavation at Gol Mod was conducted by Ts. Dorjsuren in the 1950s. The Xiongnu necropolis includes 387 burials in square ramped and circular tomb styles.

Between 2001 and 2007 a team from the Mission archéologique française en Mongolie has conducted excavations of elite tombs at Gol Mod (Desroches and André 2007). The skeletal remains of one individual from Gol Mod are held in the NUM collection and are included in this data sample.

5.4.2.9. Khanaan Uul (KU)

Latitude and Longitude: 47° 07' 44.5" N 108° 55' 09.5" E

No site report or other publications are available regarding the excavations at Khanaan Uul. The NUM collections catalog states that this site is located in Khentii province in eastern Mongolia. This site is classified as a Xiongnu period cemetery, based on burial architecture and grave good types. One individual from this site is included in this sample.

5.4.2.10. Khudgiin Am (KGA)
Latitude and Longitude: 47° 43' 58.3" N 101° 55' 32.4" E

No excavation reports or other publications on this site were available, but the NUM collections catalog states Khudgiin Am is located in Arkhangai province in central Mongolia. The burials are classified as Xiongnu period, based on burial style. The remains of two individuals were analyzed from this site.

5.4.2.11. Mankhan (MK)
Latitude and Longitude: 47° 24' 19.4" N 092° 06' 01.1" E

No publications are available on the excavations at Mankhan, however the NUM collections catalog records state that this site is located in Khovd province, western Mongolia. It is classified as a Xiongnu period cemetery. The remains of two individuals were analyzed from this site.

5.4.2.12. Noin Uul (NU)
Latitude and Longitude: 43° 16' 37" N 101° 52' 34" E

The Xiongnu necropolis of Noin Uul is located in Tuv province, central Mongolia. The site was first explored in 1924 with the Kozlov expedition's excavation of twelve tombs. Excavation resumed at the site in 1954-1955 led by Ts. Dorjsuren. Research at Noin Uul has been conducted by a Russian team led by N. Polos'mak since 2006.

The Noin Uul complex includes ostentatious square ramped tombs as well as more modest stone ring burials. The tombs at Noin Uul have yielded extraordinary and well-preserved artifacts. Silk and wool textiles, chariots, lacquered objects, horseriding accoutrements, and weapons are among the many goods found within these elite tombs (Salmony 1936, Polos'mak et al. 2008). One individual from this site is included in this data sample.

5.4.2.13. Solibo Uul (SU)
Latitude and Longitude: 47° 43' 58.3" N 101° 55' 32.4" E

Excavation reports or other publications about Solibo Uul are unavailable. The NUM collections catalog indicates that this site is located in Arkhangai province, central Mongolia. The burials in this cemetery date to the Xiongnu period. Two individuals from this site are included in this sample.

5.4.2.14. Songino Khairkhan (SK)
Latitude and Longitude: 47° 47' 16.0" N 106° 36' 30.9" E

No site reports or other publication are available for the excavations at Songino Khairkhan. The NUM collection catalog records state that the site is located in Tuv province, central Mongolia. The cemetery includes burials from the Xiongnu and Mongol periods. The remains of two Xiongnu individuals were analyzed for this study.

5.4.2.15. Takhiltin Khotgor (TK)
Latitude and Longitude: 47° 24' 19.4" N 092° 06' 01.0" E

Takhiltin Khotgor is situated in the foothills of the Altai mountains in Khovd province, western Mongolia. Two small stone ring graves were excavated in 1960 by Tseveendorj after identifying about 60 burials at this site. Excavation of two large square ramped tombs was conducted by Navaan (1999) between 1987 and 1990. In 2006 the cemetery was systematically mapped by Bryan Miller (2007) and contains 132 tombs, 27 of which are large stone ramped tombs. The Khovd Archaeological project excavated one of these large square ramped tomb complexes in 2007, as well as the small circular satellite burials associated with three tomb complexes. The skeletal remains from the 2007 excavations have been curated at the National Museum of Mongolia. Four individuals from the earlier excavations are included in this sample.

5.4.2.16. Tamiriin Ulaan Khöshöö (TUK)

Latitude and Longitude: 47° 45' 57.8" N 102° 26' 51.9" E

This site was excavated in 2005 by a collaborative project between the Silk Road Foundation and the National University of Mongolia. It is located in the Tamir river valley near the Orkhon river. The area around Tamiriin Ulaan Khöshöö contains burial grounds from the Neolithic, Bronze Age, and Mongol periods (Purcell and Spurr 2006). Previous excavations at this site by Zagd Batsaikhan revealed 287 stone ring burials. Eleven individuals from this site were included in this study.

5.4.2.17. Tarvagatain Am (TA)

Latitude and Longitude: 47° 24' 19.4" N 092° 06' 01.1" E

Site reports and other publications were unavailable for this site. The NUM collection records state that this site is located in Khovd province, western Mongolia. It dates to the Xiongnu period. One individual is included in this sample.

5.4.2.18. Tevsh Uul (TU)
Latitude and Longitude: 44° 40' 23.4" N 102° 22'36.6" E

The cemetery of Tevsh Uul is located in the Duut valley of the Baga Tevsch mountain in Uvurkhangai province in central Mongolia. Bronze Age burial mounds near Tevsh Uul were first excavated in the late 1960s by V. V. Volkov (Volkov 1967: 37). Xiongnu period graves at Tevsh Uul were excavated between 1972 and 1977 (Tseveendorj 1985). Radiocarbon dates of wood samples from Xiongnu burials date them to 50 BCE – 250 CE (Brosseder et al. 2011). This is a type site of what Honeychurch (2014: 124-125) refers to as the "Ulaanzuukh-Tevsh culture." Seven Xiongnu period individuals from this site are included in this sample.

5.5. Jilin University Collection

The collection of human skeletal remains at Jilin University's Research Center for Chinese Frontier Archaeology contains remains over 4,000 individuals from many sites across northern China. The entire collection is housed in climate-controlled lab space within the Research Center.

Cranial remains were labeled and individually boxed. Postcranial remains were stored separately, but were also labeled individually with the site name and burial number. Some tombs contained multiple individuals and the majority of these individuals were labeled with unique catalog numbers. In some instances I was not able to distinguish the remains for multiple individuals from the same tomb. In these cases, all individuals from that tomb were omitted from my sample. I was able to analyze all cranial remains for the sample I selected. Some postcranial remains were omitted because of time constraints.

I was provided with a large private room next to the skeletal storage area for analyzing remains. The room contained a large table suitable for laying out the skeletons. The lighting was adequate for analysis and photography. The purpose of including data from Taojiazhai in my research sample was to provide a comparative group of sedentary, agricultural individuals in order to identify differences in health and diet that occur with different subsistence strategies and social settings.

5.5.1. Han Dynasty Site

5.5.1.1. Taojiazhai (TJZ)

Latitude and Longitude: 31° 25' 8.47" N 121° 19' 14.88" E

This site is located north of the city of Xining in Qinghai province, People's Republic of China. The cemetery sits in the Huang river valley with the Beichuan River to the east and the Daye mountains to the west. Based on the style of tomb construction and grave goods, this site was in use between 200 BCE and 400 CE, from the Han through Jin dynasties (Qinghai Provincial Institute of Cultural Relics and Archaeology 2007).

A total of 378 individuals were excavated at Taojiazhai between 2002 and 2005. The burials were arranged in large clusters with each individual interred within a wooden coffin. The large clusters are considered to represent family groups (Zhang 2013:325).

This site is located in a frontier zone between the nomadic groups in Xinjiang province and the agricultural communities of the North China plain. This population most likely practiced some pastoralism along with cereal grain agriculture (Zhang 2013:341). The population of Taojiazhai most likely differs in ethnicity and subsistence mode from a population located in the core area of the North China plain. However, the evidence that they are practicing agriculture and had a significant grain component to their diet makes them an appropriate population to compare to the nomadic pastoralists of the Xiongnu sample. I was able to collect data from the skeletal remains of 231 individuals from this site.

5.6. Conclusion

This chapter provides some background information on each site included in this data sample and the conditions under which the remains were stored and analyzed. The skeletal remains from cemetery sites in Mongolia represent individuals from across the Bronze Age landscape and the geographic area of Xiongnu influence. The data from individuals analyzed from the Taojiazhai site provide a comparative sample to the data from individuals from the Xiongnu period. I hypothesize that, in some aspects, health and diet of Xiongnu subjects will be more similar to that of Han agriculturalists than to Bronze Age Mongolian nomads. In the next chapter, the methods used to analyze and collect data from the skeletal materials from these sites will be discussed.

Chapter 6: Data Collection Methods

6.1. Introduction

Based on the bioarchaeological models described in Chapter 4, data in several standard categories were recorded from skeletal remains located in collections in Mongolia and China. The study sample included three different populations for comparison purposes: Bronze Age Mongolian nomadic people, Iron Age Xiongnu people, and people living within the Han Empire in China.

Observations were recorded and coded according to the standards set forth in *Standards for Data Collection from Human Skeletal Remains* (Buikstra and Ubelaker: 1994) and entered into a computer database using Osteoware, a software program for documenting skeletal data developed by the Smithsonian Institution's National Museum of Natural History (available at osteoware.si.edu). Photographs were taken of all skeletal abnormalities and pathological lesions, as well as general reference photographs of all crania.

To control for intra-observer error, observations were re-recorded from a random 5% of the sample. There was good consistency between the first and second sets of observations. Following are descriptions of the different types of data gathered and the methods by which these data were recorded for the analyses performed to investigate aspects of health status, diet, and population during the Xiongnu Empire.

6.2. Inventory of Human Remains

Prior to analysis, each set of individual remains was laid out, and an inventory of skeletal elements present was recorded, including completeness and state of preservation according to guidelines set forth in Bello et al. (2006). Very little cleaning was required as most of the material had been previously cleaned analyzed, but when necessary the remains were cleaned according to the guidelines described in *The Human Bone Manual* (White and Folkens 2005:335) to remove surface debris. The presence and condition of each tooth was inventoried according to Buikstra and Ubelaker (1994:5-14).

All cranial and post-cranial materials were stored individually, so it was not necessary to determine minimum number of individuals (MNI). When analyzing post-cranial remains, I did verify that there were no duplicated skeletal elements, and that the remains appeared to be consistent in size, development, and taphonomic characteristics.

6.3. Estimation of Age at Death

There are several morphological features of the skeleton and dentition that vary with age in a manner that is similar among all humans. Based on these skeletal features, the age of each individual was assigned based on the categories recommended by Buikstra and Ubelaker (1994). These age categories are described in Table 6.1.

Table 6.1. Age categories used in this study.

Age category	Description
B-4	Birth - 4 years
5-9	5-9 years
10-19	10-19 years
SA	Subadult (< 19 years)
YA	Young Adult (20-34)
MA	Middle Adult (35-50)
OA	Old Adult (50+)
IA	Indeterminate Adult (adult 20+ of unknown age)

Age-at-death can be estimated to a much narrower range in juveniles than in adult remains. Sub-adult age was determined using rate of post-cranial epiphyseal union (Krogman and Iscan 1986; Redfield 1970; Suchey et al. 1984; Ubelaker 1989a, 1989b), and eruption patterns and dental development (Liversidge 1994; Moorees et al. 1963). Multiple estimation methods were used to maximize the accuracy of age at death estimates.

Age estimations for adults were made based on the morphology of the pubic symphyseal faces (Brooks and Suchey 1990; Todd 1920, 1921), auricular surface of the ilium (Buckberry and Chamberlain 2002; Lovejoy et al. 1985), sternal rib ends (Loth and Işcan 1989; Yoder and Powell 2001), and cranial suture closure (Meindl and Lovejoy 1985). These methods were used together, when the appropriate elements were present, to provide a more reliable estimate than any one method alone.

When no specific age category could be determined, individuals were designated as “sub-adult” or “adult.” Estimating age at death provides paleodemographic data that were used to look for patterns within the sample population.

6.4. Estimation of Sex

Several elements in the adult skeleton can be used to assess the sex of an individual. The pelvis is most commonly used because it has several features that are markedly different between males and females (Phenice 1969). There are also several characteristics of the skull that exhibit sexual dimorphism (Buikstra and Ubelaker 1994:19-21). General robusticity of the post-cranial skeleton can also provide some sense of whether an individual is male or female (Dibennardo and Taylor 1983; Spradley and Jantz 2011). All available morphological features (depending on completeness and preservation of skeletal elements) were used in assigning an estimation of sex for each adult individual, as this provides a more reliable estimate than any one method alone (Buikstra and Ubelaker 1994:15). If no sexually dimorphic elements were present, or if sexually dimorphic traits were ambiguous, sex was recorded as "indeterminate."

Estimating sex for sub-adult individuals is not usually attempted, as sexual skeletal differences do not develop until puberty (Vlak et al. 2008; White and Folkens 2005:385-386). I used the standard methods described above to attempt to estimate sex for older sub-adult remains, but for pre-pubescent individuals or if sex could not be determined, no sex was assigned ("indeterminate").

6.5. Dental Health

In addition to an overall dental inventory, I assessed dental health by recording the presence of antemortem tooth loss (AMTL), dental caries, and temporomandibular joint (TMJ) disease. For AMTL and dental caries, the affected tooth or socket was recorded. Any observed degenerative changes to the temporomandibular joint were also recorded.

6.5.1. Antemortem tooth loss (AMTL)

An instance of antemortem tooth loss (AMTL) was recorded when a tooth was absent from a socket and any evidence of alveolar resorption was observed macroscopically (see Figure 6.1). AMTL was distinguished from postmortem tooth loss by the presence of a bony response. For the statistical analyses, the frequency of individuals affected by AMTL was used, so multiple occurrences in the same individual were recorded as one individual with AMTL present.

Figure 6.1. Examples of antemortem tooth loss. Arrows and circles indicate areas of alveolar bone resorption. National University of Mongolia (top left: AT_145 Tevsch Uul, all others: AT_630 Kheviin Am). Photographs by Veronica A. Joseph.

6.5.2. Dental caries

Carious lesions appear as dark eroded regions of tooth enamel and were observed macro- and microscopically under bright light (Figure 6.2). The tooth number, affected surface (buccal/labial, lingual, occlusal, interproximal), and extent of lesion were recorded. As with AMTL, the frequency of individuals affected by caries was used for statistical analyses, so multiple occurrences in the same individual was recorded as one individual with dental caries present.

Figure 6.2. Example of dental caries at the cementoenamel junction. Arrows indicate carious lesions. Jilin University (XT M20:4 Taojiazhai). Photograph by Veronica A. Joseph.

6.5.3. Temporomandibular joint (TMJ) degeneration

Osteoarthritic changes of the temporomandibular joint (TMJ) can provide information about dietary composition as it is influenced by the stress on the TMJ caused by chewing (Figure 6.3). Any arthritic changes (osteophyte formation, eburnation, erosion, porosity) on the mandibular condyle or in the mandibular fossa were recorded. Any observable changes on the left or right side of either element was recorded as present for that individual.

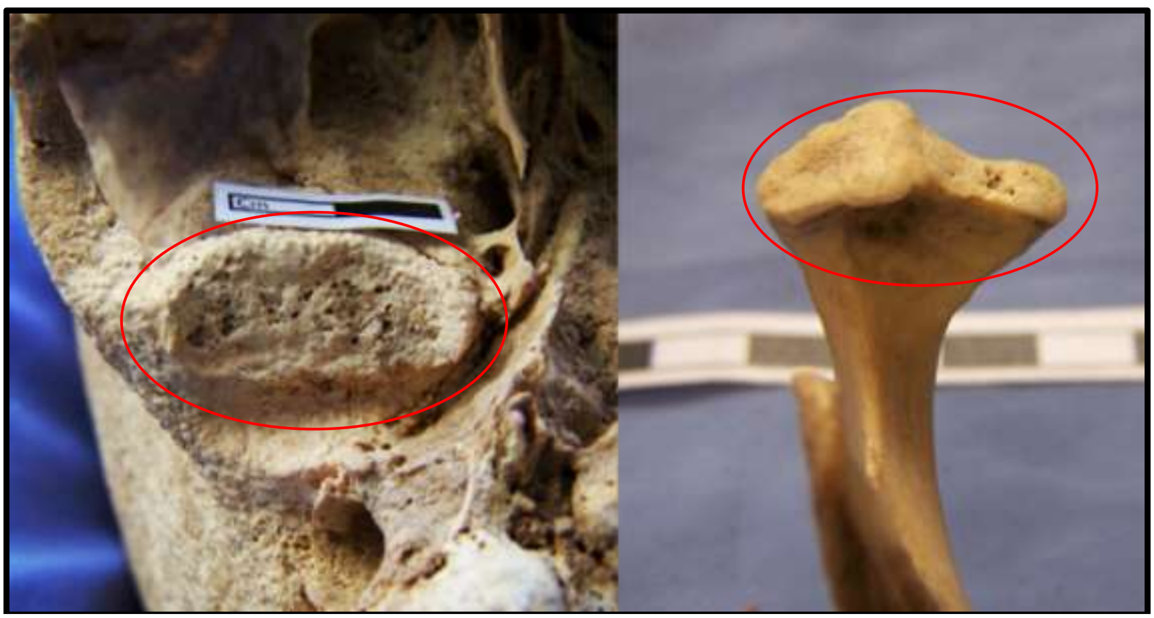


Figure 6.3. Porosity and erosion of the mandibular fossa (left) and mandibular condyle (right). Circles indicate affected areas. National University of Mongolia (left: AT_728 Tamiriin Ulaan Khöshöö, right: AT_610 Uushigiin Uvur). Photographs by Veronica A. Joseph.

6.6. Nutritional Stress

Several types of skeletal lesions can indicate periods of stress or nutritional inadequacy during life. All observations of enamel hypoplasias (EH), porotic hyperostosis (PH), and osteoperiostitis (OP) were recorded.

6.6.1. Enamel hypoplasias (EH)

Enamel hypoplasias (EH) are defects in tooth enamel (Figure 6.4). They can occur when nutritional stress or disease during tooth formation (approximately 4-16 years of age) interrupts the deposition of enamel. These defects appear as continuous horizontal grooves across the tooth surface. I recorded the presence and tooth number of enamel hypoplasias, but for analytical purposes any instance of enamel hypoplasia (EH) was recorded as one individual with EH present.

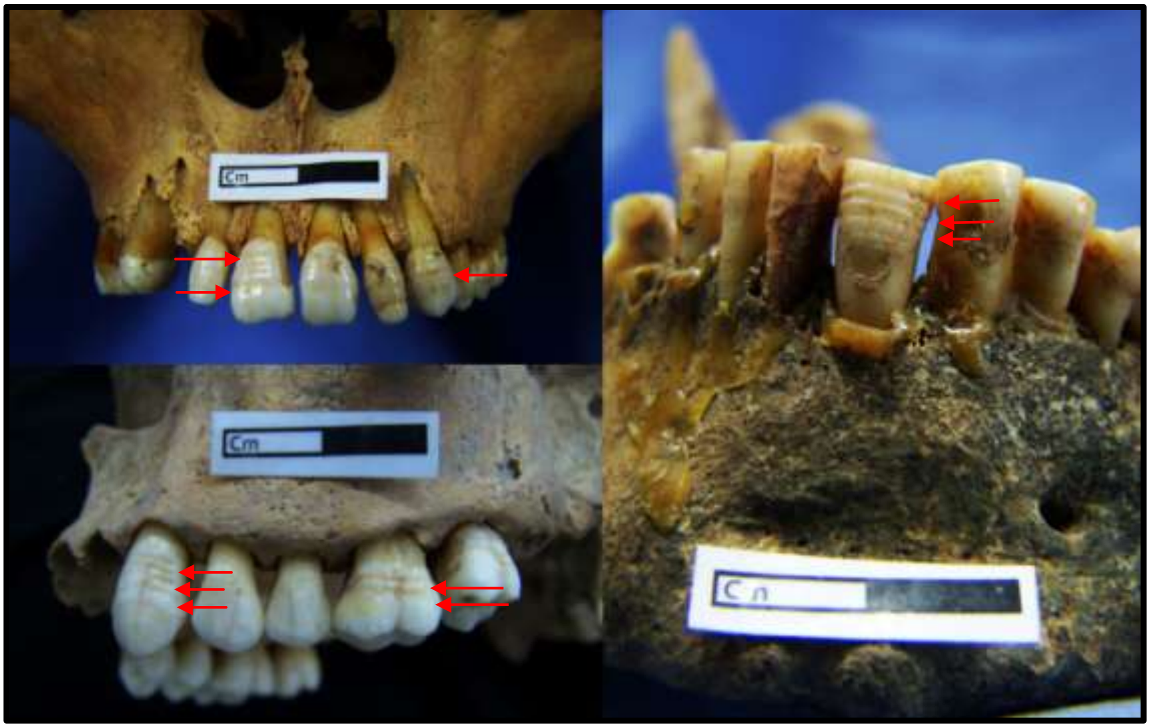


Figure 6.4. Enamel hypoplasias in maxillary incisors (top left), maxillary canine and molar (bottom left), and mandibular incisor (right). Arrows indicate locations of enamel hypoplasias. National University of Mongolia (top left: AT_294 Buural Uul, right: AT_121 Chandmani Uul) and Jilin University (bottom left: XT M10:5 Taojiazhai). Photographs by Veronica A. Joseph.

6.6.2. Porotic hyperostosis (PH)

Nutritional deficiencies can cause porotic hyperostosis, which presents macroscopically as areas on the cranium of pitting and porosity (Figure 6.5). These lesions are visible on the outer table of the cranial vault and orbital roof (cribra orbitalia). I recorded the presence of these lesions and noted their severity, and whether lesions were active or healing.

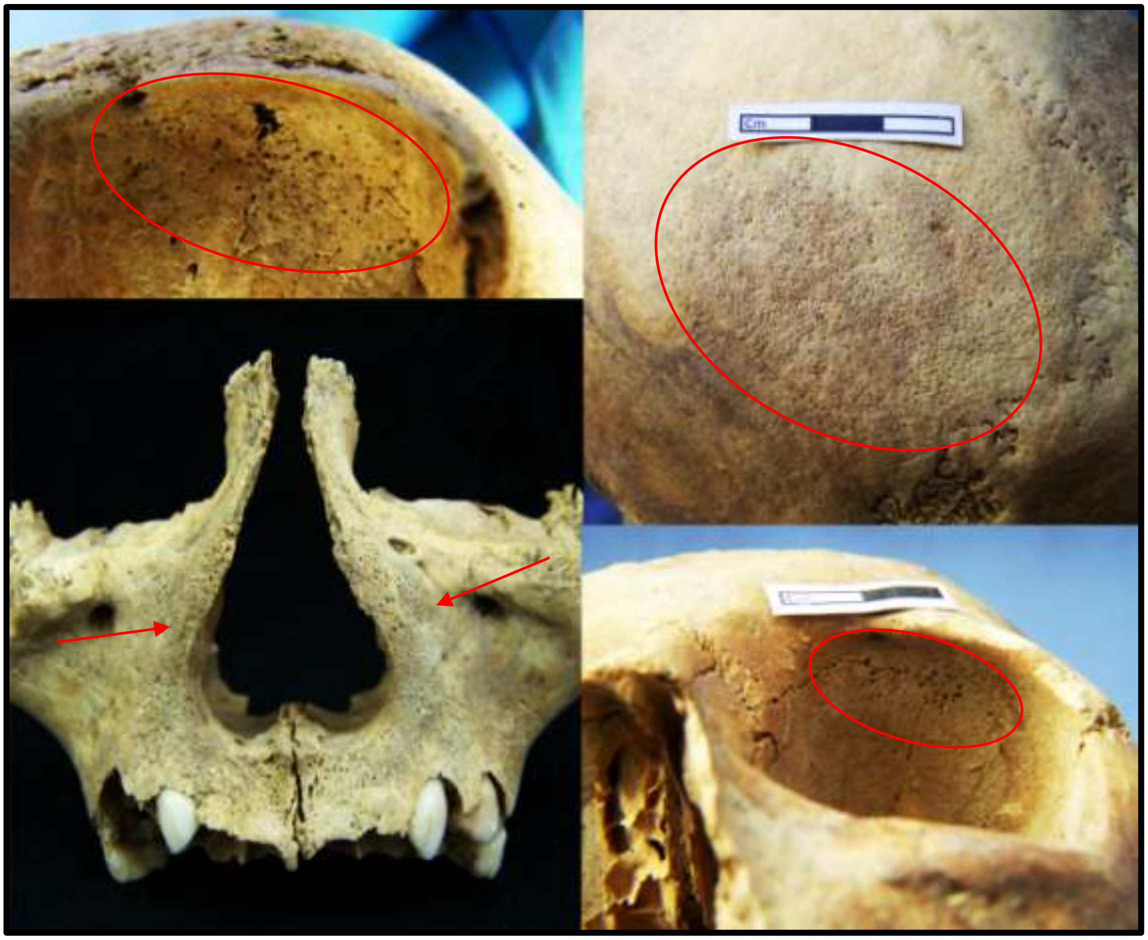


Figure 6.5. Examples of porotic hyperostosis: healing lesions of orbital roof (top left, bottom right), healing lesions on left parietal (top right), active lesions of maxillae (bottom left). Arrows and circles indicate location of lesions. National University of Mongolia (top left: AT_749 Ugumuur, top right: AT_366 Mankhan, bottom right: AT_274 Solibo Uul) and Jilin University (bottom left: XT M2:7 Taojiazhai). Photographs by Veronica A. Joseph.

6.6.3. Osteoperiostitis (OP)

Osteoperiostitis (OP) is an inflammation of the periosteum surrounding a bone caused by trauma, infection, or nutritional deficiency (Ortner 2003). It is identified on skeletal elements as striations, pitting, or plaque-like new bone formation on the cortical surface of the bone (Figure 6.6). I recorded the element and location of any lesions observed. Any instance of osteoperiostitis was considered as present for that individual in my analyses.

Figure 6.6. Osteoperiostitis of mandibular body (top) and distal left femur (bottom). Circles indicate areas of osteoperiostitis. Jilin University (top: XT M9:3, bottom: XT M54:10 Taojiazhai). Photographs by Veronica A. Joseph.

6.7. Trauma and Activity-Related Diseases

All skeletal elements present were examined for evidence of trauma or other pathological lesions and, if present, the location and type of pathology was recorded in the Osteoware Pathology module, based on the protocols set forth in Buikstra and Ubelaker (1994:119-120). Pathological lesions were observed using macroscopic and microscopic (10x loupe) techniques to determine the type of lesion and to distinguish antemortem (before death) or perimortem (at or near the time of death) lesions from damage caused by postmortem (after death) taphonomic processes.

6.7.1. Trauma

Traumatic injuries observed in these samples included fractures of the cranium and longbones, depression injuries, and projectile trauma (Figures 6.7, 6.8, and 6.9). Affected skeletal element, location, type of trauma, and any evidence of healing were recorded. For the purposes of this analysis, any instance of antemortem or perimortem trauma, including multiple traumatic injuries in the same individual, was recorded as "present" for that individual. Cranial and post-cranial trauma were recorded separately.

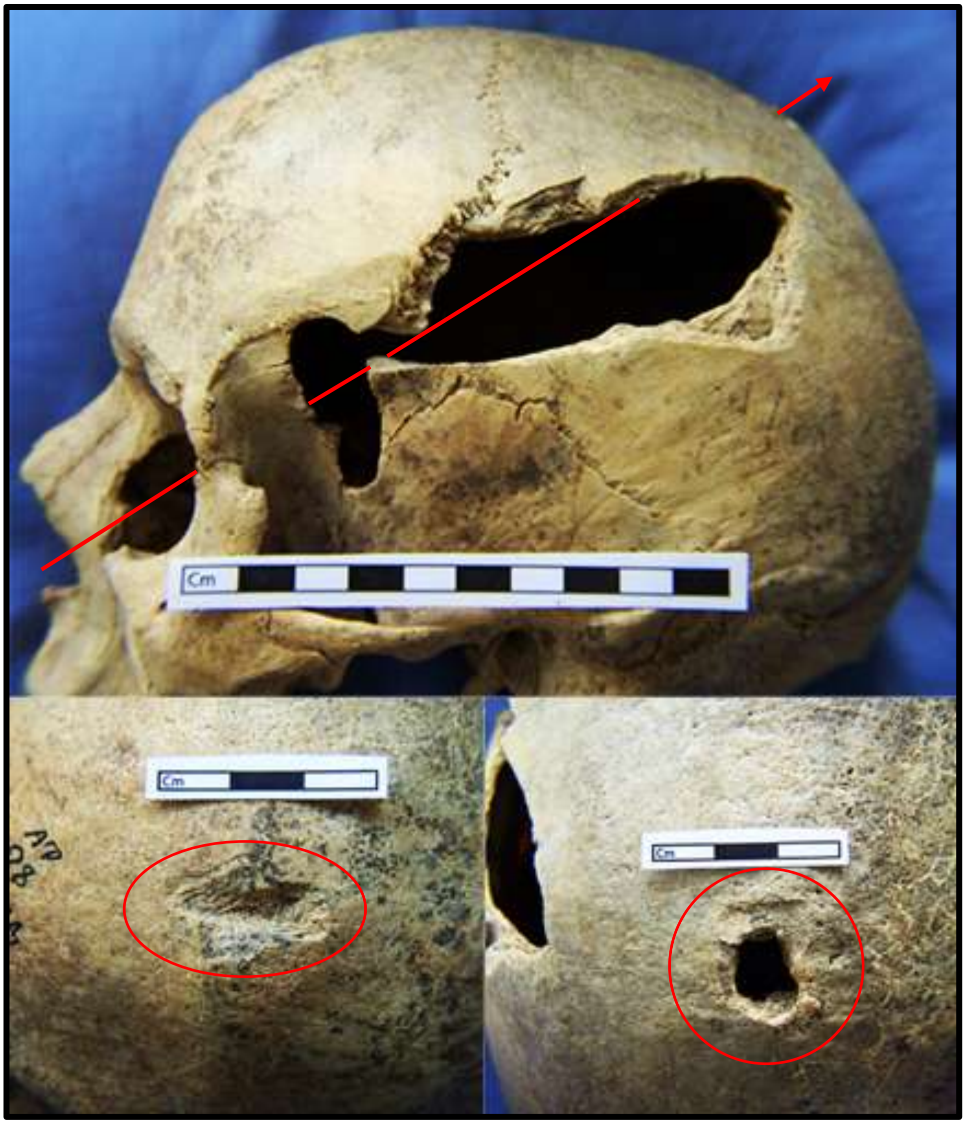


Figure 6.7. Instances of projectile (top and bottom right) and sharp force (bottom left) trauma in a single individual. Arrows and circles indicate locations of traumatic injury. National University of Mongolia (AT_098 Changmani Uul). Photographs by Veronica A. Joseph.

Figure 6.8. Healed nasal fracture (left) and perimortem sharp force trauma to the right maxilla (right). Arrows and circles indicate location of trauma. National University of Mongolia (left: AT_140 Chandmani Uul) and Jilin University (XT M9:8 Taojiazhai). Photographs by Veronica A. Joseph.

Figure 6.9. Examples of post-cranial trauma. Rib fracture with minimal healing activity (top) and misaligned healed fracture of left radius (bottom). Arrows indicate location of trauma. Jilin University (top: XT M16:1, bottom: XT M52:1 Taojiazhai). Photographs by Veronica A. Joseph.

6.7.2. Degenerative joint disease (DJD)

Degenerative joint diseases (DJD), such as osteoarthritis, are the result of advanced age and repetitive activities. These diseases can be seen as osteophytic lipping, porosity, and eburnation on the articular surfaces of the joints (Figure 6.10). I recorded any observations of degenerative changes of the major joints: shoulder, elbow, wrist, hip, knee, and ankle. The location and severity of the lesions was noted for any articular surfaces present. If the articular surface of any bone involved in a joint was affected, i.e. distal humerus, proximal ulna, or proximal radius in the case of the elbow joint, the individual was scored as DJD present for that joint. For the purposes of statistical analysis, the frequency of DJD was grouped into upper (shoulder, elbow, wrist) and lower (hip, knee, ankle) joints. If a single individual displayed degenerative changes in multiple upper or lower joints I recorded it as present in one individual. If one individual displayed upper and lower degenerative joint disease that individual was recorded once in each category.

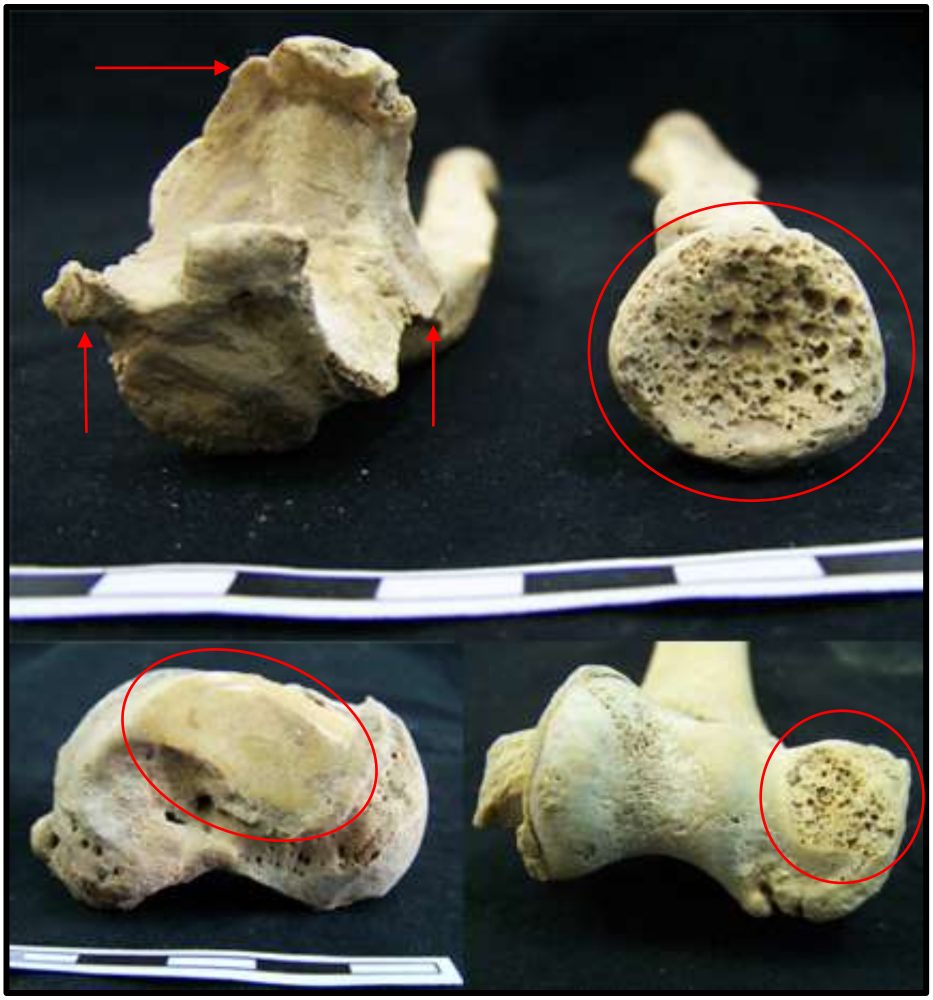


Figure 6.10. Examples of DJD: lipping and porosity of proximal right ulna and radius (top), eburnation of left talus (bottom left), and eburnation and porosity of distal left humerus (bottom right). Arrows and circles indicate location of degenerative lesions. Jilin University (top: XT M62:2, bottom left: XT M20:4, bottom right: XT M62:3 Taojiazhai). Photographs by Veronica A. Joseph.

6.8. Cranial Measurements

Cranial and dental measurements can be used to determine relatedness between groups of people. Although environmental factors do affect skeletal morphology, cranial shape is closely linked to genes (Buikstra et al. 1990). Similarities in cranial morphology can indicate the degree of relatedness between groups of people, which in turn can be used to evaluate models of the migration or dispersal of past populations (Hanihara 2006, Pietrusewsky 2006).

I recorded cranial and mandibular measurements (Buikstra and Ubelaker 1994:71-78) to generate an R Matrix, F_{ST} estimate, Relethford-Blangero residuals, and biological distance using the RMET 5.0 software package (Relethford 2003).

Initially, 58 cranial measurements were observed for each individual in the sample. These measurements were taken from standard cranial landmarks used to record craniofacial data (Howells 1973, Moore-Jansen et al. 1994). The landmarks used to record cranial measurements used in this study are described in Table 6.2 and depicted in Figure 6.11.

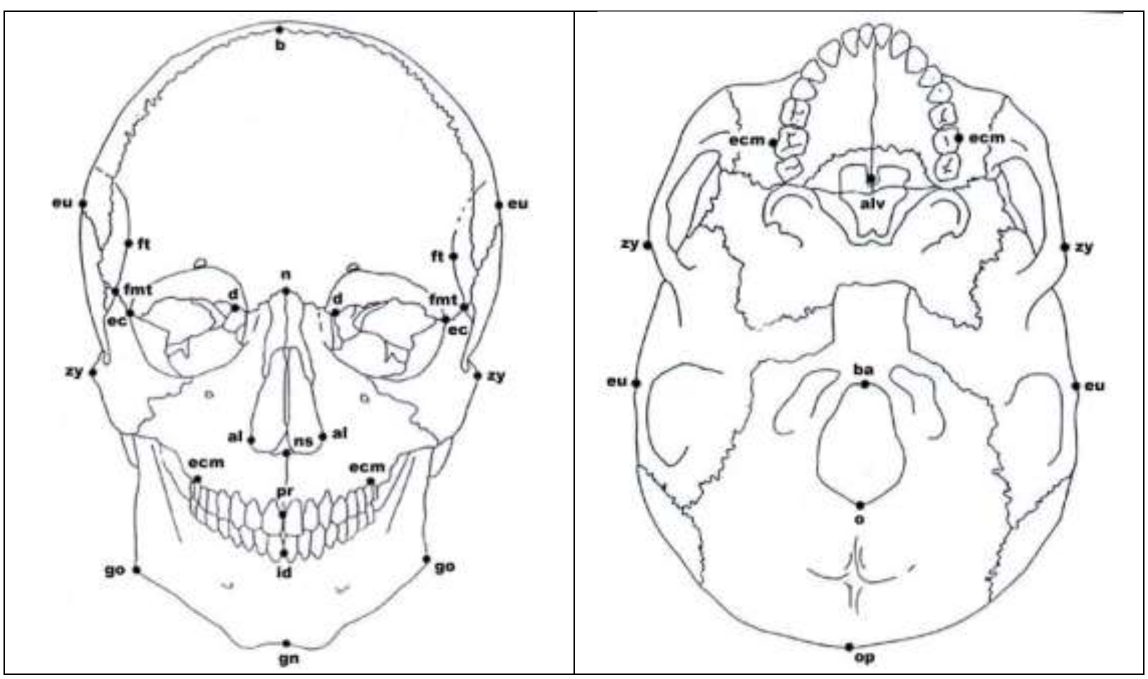


Figure 6.11. Cranial landmarks used to record craniofacial measurements, anterior (left) and inferior (right) (Moore-Jansen et al. 1994:44, 47).

Table 6.2. Cranial landmarks used in cranial measurements and their definitions (abbreviations correspond to labels in Figure 6.11). Definitions from Buikstra and Ubelaker (1994) and Howells (1973).

Landmark	**Definition**
Alare (al)	Instrumentally determined as the most lateral points on the nasal aperture in a transverse plane (paired).
Alveolon (alv)	The point on the hard palate where a line drawn through the most posterior points of the alveolar ridges crosses the midline.
Basion (ba)	The midline point on the anterior margin of the foramen magnum.
Bregma (b)	The ectocranial midline point where the coronal and sagittal sutures intersect.
Dacryon (d)	The point on the medial border of the orbit at which the frontal, lacrimal, and maxilla intersect (paired).
Ectoconchion (ec)	The intersection of the most anterior surface of the lateral border of the orbit and a line bisecting the orbit along its long axis (paired).
Ectomolare (ecm)	The most lateral point on the outer surface of the alveolar borders of the maxilla (paired).
Euryon (eu)	Instrumentally determined ectocranial points on opposite sides of the skull that form the termini of the line of greatest cranial breadth (paired).
Glabella (g)	The most anterior midline point on the frontal bone.
Nasion (n)	The point of intersection between the frontonasal suture and the midsagittal plane.
Nasospinale (ns)	The point where a line drawn between the inferior-most points of the nasal aperture crosses the midsagittal plane.
Opisthocranion (op)	Instrumentally determined most posterior point of the skull not on the external occipital protuberance.
Prosthion (pr)	The most anterior point in the midline on the alveolar processes of the maxillae.
Zygion (zy)	Instrumentally determined as the most lateral point on the zygomatic arch (paired).
Zygomaxilare (zm)	The intersection of the zygomaxillary suture and the limit of the attachment of the masseter muscle of the facial surface.

6.9. Statistical Analytical Methods

6.9.1. Univariate statistics

The analysis of health status data involved the use of univariate statistical methods. Frequency distributions were created for each pooled sample group in each data category. I tested the statistical significance of the difference between the frequency of two group using Fisher's Exact Test. This is the best test for comparing data from small samples. I set the level of significance at p = 0.10.

6.9.2. R Matrix biological distance analysis

For multivariate analyses using the RMET software, 16 cranial measurements were chosen that represent the overall shape of the cranial vault, upper face, and nasal and orbital areas. Descriptions of the 16 craniofacial measurements used in this analysis are listed in Table 6.3 and depicted in Figures 6.12 through 6.14.

In generating an R Matrix there can be no missing data values, so any missing values were calculated using the imputation function in SPSS 22.0 in cases where certain measurements could not be obtained because of damage or deterioration of cranial elements. All measurements were transformed to z-scores prior to analysis to account for sex differences using the summary statistics (mean and standard deviation) for males and females from each population.

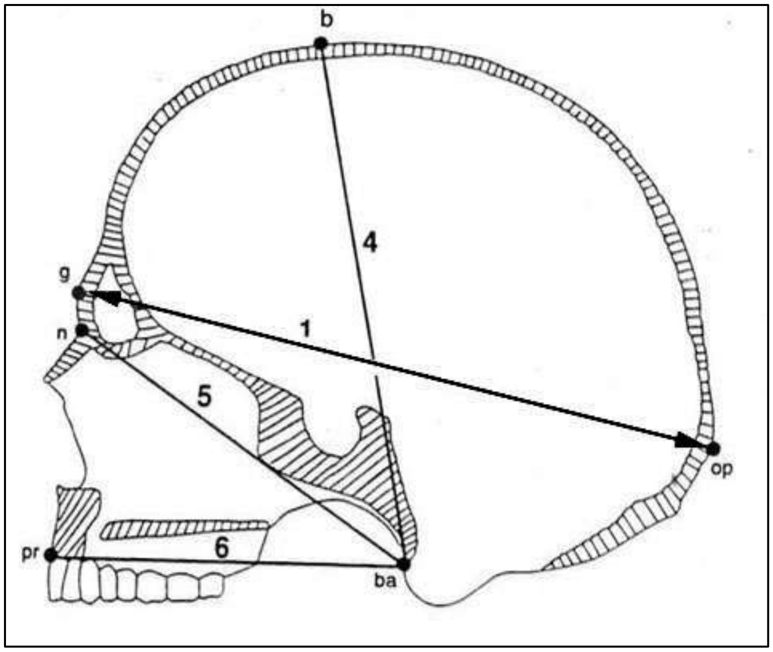


Figure 6.12. Cranial measurements, lateral view (after Moore-Jansen et al. 1994:49). See Table 6.3 for description of craniofacial measurements used in this study.

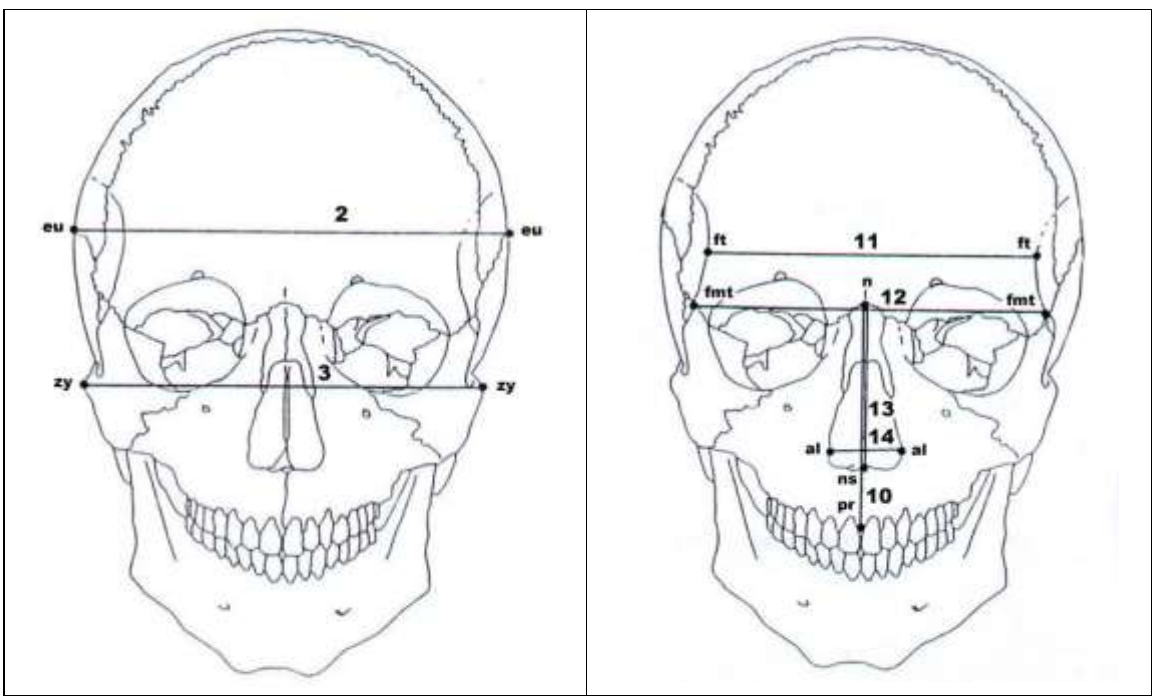


Figure 6.13. Cranial measurements, anterior view (after Moore-Jansen et al. 1994:50, 53). See Table 6.3 for description of craniofacial measurements used in this study.

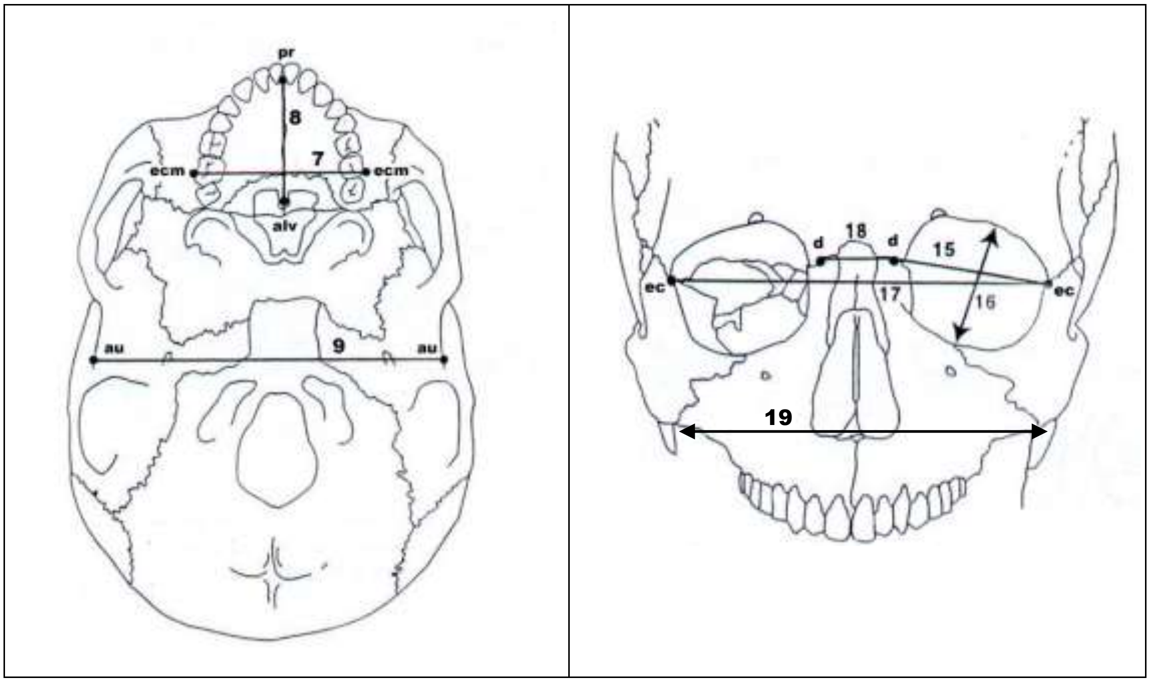


Figure 6.14. Cranial measurements, inferior view (left) and orbital area (right) (after Moore-Jansen et al. 1994:52, 54). See Table 6.3 for description of craniofacial measurements used in this study.

Table 6.3. Cranial dimensions used in biodistance analysis and their definitions. Number refers to depiction of measurement in Figures 6.12 through 6.14. (after Buikstra and Ubelaker 1994 and Howells 1973).

1. Maximum cranial length (GOL)	Distance between glabella (g) and opisthocranion (op) in the midsagittal plane, measured in a straight line.
2. Maximum cranial breadth (XCB)	Maximum width of the skull perpendicular to the midsagittal plane wherever it is located (eu to eu).
3. Bizygomatic breadth (ZYB)	Direct distance between the most lateral points on the zygomatic arches (zy-zy).
4. Cranial height (BBH)	Direct distance from the lowest point on the anterior margin of the foramen magnum (ba) to bregma (b).
5. Upper facial depth (BNL)	Direct distance from nasion (n) to basion (ba).
6. Lower facial depth (BPL)	Direct distance from prosthion (pr) to basion (ba).
7. Maxillo-alveolar breadth (MAB)	Maximum breadth across the alveolar borders of the maxilla measured on the lateral surfaces at the location of the second maxillary molars (ecm-ecm).
8. Maxillo-alveolar length (MAL)	Direct distance from prosthion (pr) to alveolon (alv).
10. Upper facial height (NPH)	Direct distance from nasion (n) to prosthion (pr).
13. Nasal height (NLH)	Direct distance from nasion (n) to the midpoint of a line connecting the lowest points of the inferior margin of the nasal notches (ns).
14. Nasal breadth (NLB)	Maximum breadth of the nasal aperture (al-al).
15. Orbital breadth (OBB)	Laterally sloping distance from dacryon (d) to ectoconchion (ec).
16. Orbital height (OBH)	Direct distance between the superior and inferior orbital margins.
17. Biorbital breadth (EKB)	Direct distance between right and left ectoconchion (ec-ec).
18. Dacryon breadth (DKB)	Direct distance between left and right dacryon (d-d).
19. Zygomaxillary breadth (ZMB)	Direct distance between left and right zygomaxillare (zm-zm).

6.10. Conclusion

In this chapter, the methods used to collect different types of data used in the present research were described. These data include standard indicators of age, sex, diet, disease, nutritional status, trauma, activity patterns, and biological relatedness. These methods were followed to ensure that observations were recorded accurately and consistently. The next chapter describes the analyses performed with these data and the results.

Chapter 7: Data Analysis

7.1. Introduction

This chapter presents the results of the data analysis. The demographics of the sample and how the individual site samples were grouped together to address my research questions and to increase the sample size and thus the power of statistical analysis are explained. Then, the results are given with a brief interpretation, which will be discussed in greater detail in the next chapter.

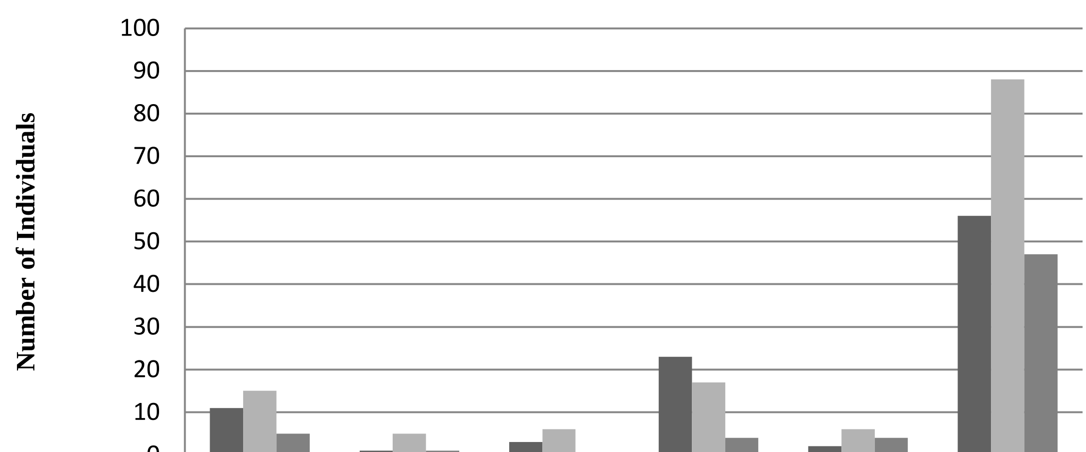
Before beginning the analysis of skeletal data to explore the hypotheses I set forth for this research project, I first examined the demographic makeup of my sample. Data were gathered from a total of 349 individuals from 27 separate cemetery sites. With the exception of Taojiazhai, the Han-period site in northwest China, the number of individuals from each site was comparatively small. Table 7.1 shows the age and sex distribution of the sample from each site. For definitions of the age category abbreviations, see Table 6.1.

Table 7.1: Age and sex distribution of sample by site.

Site	B-4	5-9	10-19	SA	YA M	YA F	MA M	MA F	OA M	OA F	AM	AF	IA	Total
TJZ	4	17	19	0	21	56	23	20	0	1	12	11	47	231
BA	0	0	1	0	0	0	0	1	0	1	0	0	0	3
BT	0	1	0	0	1	2	1	0	0	0	0	0	0	5
BU	0	0	1	0	2	5	4	0	0	1	0	0	0	13
CU	0	0	1	0	3	5	1	1	0	0	0	0	1	12
DKU	0	0	0	0	0	0	1	0	0	0	0	1	1	3
DU	0	0	0	0	0	2	0	2	0	0	1	0	2	7
ET	0	0	1	1	0	0	3	0	0	0	0	0	1	6
ES	0	0	0	0	0	0	0	1	0	0	0	0	0	1
GM	0	0	0	0	0	1	0	0	0	0	0	0	0	1
IK	0	1	0	0	0	1	0	0	0	0	0	0	1	3
KU	0	0	0	0	0	0	0	0	0	0	0	0	1	1
KA	0	0	0	0	0	0	0	1	0	1	0	0	2	4
KT	1^X	0	0	0	0	1^X	1^B	1^B	0	1^B	0	0	0	5
KGA	0	1	0	0	0	0	0	0	0	1	0	0	0	2
MK	0	0	1	0	0	1	0	0	0	0	0	0	0	2
NU	0	0	0	0	1	0	0	0	0	0	0	0	0	1
SU	0	0	0	0	0	2	0	0	0	0	0	0	0	2
SK	0	0	1	0	0	0	1	0	0	0	0	0	0	2
TK	0	0	0	0	3	0	0	0	0	0	0	1	0	4
TUK	0	0	0	0	1	1	2	3	0	0	2	0	2	11
TA	0	0	0	0	0	0	0	1	0	0	0	0	0	1
TU	0	0	0	0	4	1	1	0	0	0	0	0	1	7
UDD	0	0	0	1	0	1	1	1	0	0	0	0	1	5
UZ	1	2	0	0	1	3	0	1	0	1	0	0	1	10
US	0	0	0	0	0	1	1	0	0	0	0	0	0	2
UU	0	0	0	0	1	0	2	1	0	1	0	0	0	5

7.2. Pooled Samples

To increase the power of statistical analyses used to examine my research questions, sites from the same time period and region were grouped together to form a larger pooled sample. There are six pooled sample groups: Bronze Age West, Bronze Age East, Xiongnu West, Xiongnu Central, Xiongnu East, and Han. Figures 7.1 and 7.2 show the sex and age distribution of each of the regional groups. Below I will describe each pooled sample in greater detail.



	BAW	BAE	XW	XC	XE	TJZ
Adult M	11	1	3	23	2	56
Adult F	15	5	6	17	6	88
Adult Indet.	5	1	0	4	4	47

Figure 7.1. Sex distribution of regional samples.

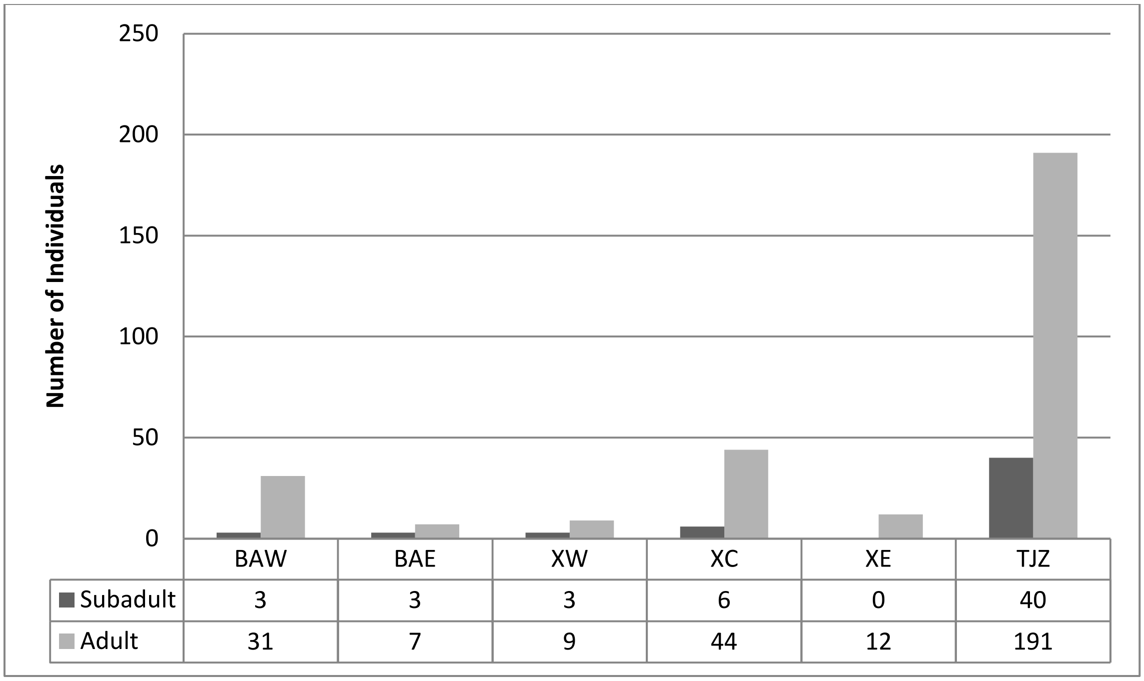


Figure 7.2. Age distribution of regional samples.

7.2.1. Bronze Age West (BW)

This grouped sample consists of the Bronze Age period pastoral-nomadic sites located in western Mongolia. Individuals from Chandmani Uul, Iagshiin Khödöö, Kheviin Am, Uliastain Dund Denj, Urgun Shireg, and Uushgiin Uvur sites were placed in this category. Khoit Tsenkher cemetery had individuals from both the Bronze Age and Xiongnu periods. The three Bronze Age individuals from Khoit Tsenkher are also included in the Bronze Age West group. There are 34 individuals in this pooled group.

7.2.2. Bronze Age East (BE)

The only Bronze Age period site located in eastern Mongolia included in this study sample is Ulaanzuukh. In other words, the Bronze Age East sample is the same as the Ulaanzuukh site sample. The total number of individuals in this group is 10.

7.2.3. Xiongnu West (XW)

The Xiongnu West grouped sample contains the individuals from Xiongnu-period sites located in Western Mongolia. Biluut II, Mankhan, Takhiltiin Khotgor, and Tarvagatain Am make up this regional sample, along with the two Xiongnu-period individuals from Khoit Tsenkher. The Xiongnu West group has a sample size of 12.

7.2.4. Xiongnu Central (XC)

This is the largest of the Mongolian grouped samples, as many of the large Xiongnu-period cemeteries are located in central Mongolia. Xiongnu Central sample includes the individuals from Burkhan Tolgoi, Buural Uul, Emeel Tolgoi, Golmod, Khudgiin Am, Noin Uul, Solibo Uul, Songino Kharkhan, Tamiriin Ulaan Khöshöö, and Tevsch Uul. There are 50 individuals in this sample.

7.2.5. Xiongnu East (XE)

The Xiongnu-period sites located in eastern Mongolia make up the Xiongnu East regional group. Delgerkhaan Uul, Duulga Uul, Erdenetsagaan, and Khanaan Uul individuals were placed in this group. This sample size is 12 individuals.

7.2.6. Han Period (H)

The individuals analyzed in this study that make up the Han period sample are all from the Taojiazhai site. This site, located in northwest China, has a total of 231 individuals.

7.3. Groups by Time Period

To look at broader trends in health and diet I grouped the samples together at the higher level of Bronze Age (B), Xiongnu (X), and Han (H). The Bronze Age group consists of the Bronze Age West and Bronze Age East samples, the Xiongnu group is made up of the Xiongnu West, Xiongnu Central, and Xiongnu East samples, and the Han group is the same as the sample from the Taojiazhai site.

7.4. Demographic Structure of Sample

The skeletal sample as a whole (n=349) contains far more adults than subadults. For the purposes of this study, any individual determined to be under 19 years of age was classified as a subadult. The entire sample included only 55 subadults (16%), the majority of whom (n=40) were from the Taojiazhai site. Of the subadults represented, there were more individuals in the older age categories. The adult portion of the sample (n=294, 84%) is made up of more young and middle aged adults than older adults.

Females make up 47% (n=138) of the adult sample, while males only make up 32% (n=95). The other 21% (n=61) of the adult sample consists of individuals whose sex could not be determined.

There are many potential biases that contribute to the age and sex makeup of any cemetery population. The population structure of an archaeological skeletal collection represents a mortality assemblage and is unlikely to reflect the structure of the living population from which it was created (Wood, et al. 1992). Paine and Harpending (1998:232) discuss four broad categories of potential biases in archaeological skeletal assemblages: 1) culture-based differences in treatment of remains; 2) taphonomic processes such as differential preservation of remains; 3) archaeological recovery methods; and 4) age and sex estimation techniques.

Infant and older adult under-representation are two well documented biases of archaeological samples. Anatomically, the remains of these individuals can be more fragile and susceptible to loss by taphonomic processes (Gordon and Buikstra 1981; Waldron 2007; Walker 1995; Walker et al. 1988). In this study, taphonomic processes are most likely responsible for the relatively few infants and older adults reprensented in the skeletal assemblage.

To minimize the effect of age and sex estimation technique biases, I rigorously adhered to the guidelines set forth in Buikstra and Ubelaker (1994) and used all available age and sex indicators in determining age and sex categories for each individual. Using indicators of the skull and pelvis to determine sex has been shown to be more accurate than either skull or pelvis indicators independently (Meindl and Lovejoy 1985). If conflicting or insufficient age and sex characteristics were present, no determination of age or sex was made. These individuals were placed into the general ‘Subadult’ or ‘Adult’ age categories, and ‘Indeterminate’ sex category accordingly.

7.5. Health and Dietary Data

The regional groupings described above were used to pool the health and dietary data collected from these individuals. I collected data on 11 dietary and health indicators, described in greater detail in Chapters 4 and5. A brief definition is given in Table 7.2.

I compared the frequencies or means of each of these 11 indicators for each pooled sample amongst males, females, all adults combined, and subadults. I also compared males to females and adults to subadults within each pooled group. Tables 7.3-7.11 present the frequency tables of these data.

The statistical significance of the difference in frequency (in other words, all health indicators except mean long bone length) was tested by using Fischer’s exact test (Fisher 1922; Upton 1992). For each comparison, I created a 2x2 contingency table to calculate the probability (p value) that the two observed frequencies originated from populations with no difference in the frequency of that indicator (the null hypothesis). If the p value was less than 0.1000, I considered that to be a statistically significant result. A p value of 0.1000 means there is a 10% probability that the null hypothesis is true. In the instance of a significant result, the direction of the frequency difference was noted. For p values between 0.2000 and 0.1000, I indicated that the result was not significant, but did include the direction of the frequency difference. Although not at the level of statistical significance, a 20% probability that the null hypothesis is true was small enough that the direction of the difference was of interest. See Tables A.1 through A.22 in Appendix A for the p values calculated by using Fisher's exact test and the direction of the frequency difference.

Table 7.2. Dietary and health indicators recorded in this study.

Indicator	Description
Antemortem tooth loss (AMTL)	Loss of teeth during life, as evidenced by some degree of alveolar resorption.
Dental Caries (Caries)	Tooth decay caused by bacterial activity.
Temporo-mandibular joint degeneration (TMJ)	Degenerative changes in the temporo-mandibular joint, including lipping, porosity, and eburnation of joint surfaces.
Enamel hypoplasias (EH)	Insufficient enamel production during tooth formation producing a defect in tooth enamel.
Porotic hyperostosis (PH)	Porosity of the outer cranial vault or orbital roof.
Osteoperiostitis/Osteomyelitis (OP)	Inflammation of bone caused by an infectious agent.
Post-cranial trauma (PCT)	Blunt or sharp force trauma, either ante- or perimortem, to the arms, legs, or torso.
Cranial trauma (CT)	Blunt or sharp force trauma, either ante- or perimortem, to the face and/or head.
Degenerative joint disease of upper body (DJD U)	Degenerative and/or arthritic changes in the shoulder, elbow, and/or wrist joints, including osteophytic lipping, porosity, and eburnation of articular surfaces.
Degenerative joint disease of lower body (DJD L)	Degenerative and/or arthritic changes in the hip, knee, and/or ankle joints, including osteophytic lipping, porosity, and eburnation of articular surfaces.

Table 7.3. Frequency of ten pathological indicators in adult males by region/time period.

MALES												
	BAW		BAE		XW		XC		XE		H	
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
AMTL	7/11	64	0	n/a	4/5	80	11/20	55	2/2	100	30/55	54
Caries	3/11	27	0	n/a	1/5	20	2/20	10	0/2	0	13/55	24
TMJ	2/11	17	0	n/a	2/5	33	5/20	25	1/2	50	5/55	9
EH	1/11	9	0	n/a	1/5	20	1/20	5	1/2	50	9/55	16
PH	3/12	25	0/1	0	2/6	33	7/23	30	0/3	0	3/57	5
OP	0/12	0	0/1	0	0/6	0	2/23	9	0/3	0	2/57	3
PCT	0/12	0	0/1	0	0/6	0	2/23	9	1/3	33	2/57	3
CT	7/12	58	0/1	0	0/6	0	3/23	13	1/3	33	4/57	7
DJD U	0/12	0	0/1	0	0/6	0	2/23	9	1/3	33	14/57	24
DJD L	0/12	0	0/1	0	0/6	0	1/23	4	0/3	0	6/57	10

Table 7.4. Frequency of ten pathological indicators in adult females by region/time period.

FEMALES												
	BAW		BAE		XW		XC		XE		H	
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
AMTL	8/15	53	2/3	67	2/3	66	7/21	33	3/4	75	36/95	38
Caries	3/15	20	0/3	0	1/3	33	8/21	38	2/4	50	32/95	34
TMJ	4/15	27	1/3	33	1/3	33	3/21	14	1/4	25	3/95	3
EH	1/15	7	1/3	33	0/3	0	5/21	24	0/4	0	18/95	19
PH	5/15	33	0/5	0	0/3	0	5/23	22	1/5	20	1/95	1
OP	0/15	0	0/5	0	0/3	0	0/23	0	0/5	0	1/95	1
PCT	0/15	0	1/5	20	0/3	0	0/23	0	0/5	0	1/95	1
CT	2/15	13	0/5	0	0/3	0	1/23	4	2/5	40	2/95	2
DJD U	0/15	0	1/5	20	0/3	0	0/23	0	0/5	0	2/95	2
DJD L	0/15	0	1/5	20	0/3	0	1/23	4	0/5	0	7/95	7

Table 7.5. Frequency of ten pathological indicators in all adults (male, female, or indeterminate) by region/time period.

ALL ADULTS												
	BAW		BAE		XW		XC		XE		H	
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
AMTL	17/30	57	2/3	67	6/8	75	21/45	47	6/9	67	71/160	44
Caries	7/30	23	0/3	0	2/8	25	11/45	24	3/9	33	47/160	29
TMJ	6/30	20	1/3	33	3/8	37	10/45	22	2/9	22	8/160	5
EH	3/30	10	1/3	33	1/8	12	7/45	15	2/9	22	28/160	17
PH	8/32	25	0/7	0	2/8	25	12/47	25	1/12	8	4/213	2
OP	0/32	0	0/7	0	0/8	0	2/47	4	0/12	0	8/213	4
PCT	0/32	0	1/7	14	0/8	0	2/47	4	1/12	8	5/213	2
CT	9/32	28	0/7	0	0/8	0	4/47	8	3/12	25	7/213	3
DJD U	0/32	0	1/7	14	0/8	0	2/47	4	2/12	17	31/213	14
DJD L	0/32	0	1/7	14	0/8	0	2/47	4	0/12	0	19/213	9

Table 7.6. Frequency of four pathological indicators in subadults by region/time period.

SUBADULTS												
	BAW		BAE		XW		XC		XE		H	
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
PH	0/2	0	0/3	0	0/1	0	2/8	25	0	0	3/31	10
OP	0/2	0	0/3	0	0/1	0	0/8	0	0	0	5/31	16
PCT	0/2	0	0/3	0	0/1	0	0/8	0	0	0	1/31	3
CT	0/2	0	0/3	0	0/1	0	0/8	0	0	0	0/31	0

Table 7.7. Frequency of ten pathological indicators in males by time period/subsistence mode.

ALL MALES BY TIME PERIOD/ECONOMIC MODE						
	Bronze Age		Xiongnu		Han	
	Freq	%	Freq	%	Freq	%
AMTL	7/11	64	17/27	63	30/55	54
Caries	3/11	27	3/27	11	13/55	24
TMJ	2/11	18	8/27	30	5/55	9
EH	1/11	9	3/27	11	9/55	16
PH	3/13	23	9/32	28	3/57	5
OP	0/13	0	2/32	6	2/57	3
PCT	0/13	0	3/32	9	2/57	3
CT	7/13	54	4/32	12	4/57	7
DJD U	0/13	0	3/32	9	14/57	24
DJD L	0/13	0	1/32	3	6/57	10

Table 7.8. Frequency of ten pathological indicators in females by time period/subsistence mode.

ALL FEMALES BY TIME PERIOD/ECONOMIC MODE						
	Bronze Age		Xiongnu		Han	
	Freq	%	Freq	%	Freq	%
AMTL	10/18	55	12/28	43	36/95	38
Caries	3/18	17	11/28	39	32/95	34
TMJ	5/18	28	5/28	18	3/95	3
EH	2/18	11	5/28	18	18/95	19
PH	5/20	25	6/31	19	1/95	1
OP	0/20	0	0/31	0	1/95	1
PCT	1/20	5	0/31	0	1/95	1
CT	2/20	10	3/31	10	2/95	2
DJD U	1/20	5	0/31	0	2/95	2
DJD L	1/20	5	1/31	3	7/95	7

Table 7.9. Frequency of ten pathological indicators in all adults (male, female, and indeterminate) by time period/subsistence mode.

ALL ADULTS BY TIME PERIOD/ECONOMIC MODE						
	Bronze Age		Xiongnu		Han	
	Freq	%	Freq	%	Freq	%
AMTL	19/33	57	33/62	53	71/160	44
Caries	7/33	21	16/62	26	47/160	29
TMJ	7/33	21	15/62	24	8/160	5
EH	4/33	12	10/62	16	28/160	17
PH	8/39	20	15/67	22	4/213	2
OP	0/39	0	2/67	3	8/213	4
PCT	1/39	2	3/67	4	5/213	2
CT	9/39	23	7/67	10	7/213	3
DJD U	1/39	2	4/67	6	31/213	14
DJD L	1/39	2	2/67	3	19/213	9

7.5.1. Comparisons within Bronze Age Groups

7.5.1.1. Bronze Age West vs. Bronze Age East

No comparisons could be made between males from the Bronze Age West (BW) and Bronze Age East (BE) groups as there was only one male in the BE group. There were no significant differences between the females from the BW and BE groups. When all adults from BW and BE are compared there are no significant differences between the groups.

The Bronze Age East adults did exhibit somewhat higher rates of post-cranial trauma ($p=0.1693$) and degenerative disease of the lower joints (DJD L) ($p=0.1795$). Cranial trauma was somewhat higher in the BW group in all adults ($p=0.1693$).

The lack of significantly different rates in all health indicators suggests that dietary makeup and rates of infectious disease were broadly similar between the Western and Eastern Bronze Age groups.

7.5.1.2. Bronze Age males vs. Bronze Age females

When males and females from all Bronze Age groups were compared to each other (pooled from BW and BE samples), the only statistically significant difference between them was in rate of cranial trauma ($p=0.0135$). Males had higher rates of cranial trauma than females.

7.5.1.3. Bronze Age adults vs. Bronze Age subadults

No pathological markers were observed in the small BW ($n=2$) and BE ($n=3$) subadult samples. There were no significant differences in the rates of porotic hyperostosis (PH), osteoperiostitis (OP), post-cranial trauma (PCT), or cranial trauma (CT) between adults and subadults from the Bronze Age sample.

7.5.2. Comparison within Xiongnu Groups

7.5.2.1. Xiongnu West vs. Xiongnu East

There were very few statistically significant differences in the frequency of any of the ten pathological markers among the Xiongnu regional groups. Xiongnu West (XW) and Xiongnu East (XE) samples showed no significant difference in the frequency of any pathological markers among males, females, or all adults combined.

7.5.2.2. Xiongnu Central vs. Xiongnu West

The Xiongnu Central and Xiongnu West samples also showed no significant differences in the frequency of any pathological markers among males, females, or all adults combined.

7.5.2.3. Xiongnu Central vs. Xiongnu East

There was a significantly (p=0.0733) higher rate of cranial trauma in females from the XE sample than XC. Rates of cranial trauma (p=0.1412) and degenerative disease in the upper joints (DJD U) (p=0.1806) were somewhat higher in adults from XE that XC.

7.5.2.4. Xiongnu males vs. Xiongnu females

The rate of dental caries was significantly (p=0.0286) higher in Xiongnu females than males. However, the rates of antemortem tooth loss (AMTL) was greater (p=0.1799) in males than females.

7.5.2.5. Xiongnu adults vs. Xiongnu subadults

The Xiongnu subadult sample was fairly small (n=9). No statistically significant differences in the rates of PH, OP, PCT, or CT between Xiongnu adults and subadults.

7.5.3. Comparison within Han Group

7.5.3.1. Han males vs. Han females

Within the Han sample, males had a significantly (p=0.0606) higher rate of AMTL than females. The frequency of DJD U was significantly higher (p<0.0001) in males than females. Although not at the level of significance, males had higher rates of arthritic changes of the temporo-mandibular joint (TMJ, p=0.1432), PH (p=0.1485), and CT (p=0.1979) than females. Overall, males appear to have experienced higher incidence of nutritional stress than females.

7.5.3.2. Han adults vs. Han subadults

Han subadults had significantly higher rates of PH (p=0.0458) and OP (p=0.0148) than Han adults. This would suggest that subadults were more susceptible to infectious disease and nutritional deficiencies, or were less likely to survive these stressors, thereby being represented in the cemetery population.

7.5.4. *Bronze Age vs. Xiongnu*

7.5.4.1. Bronze Age West (BW) vs. Xiongnu West (XW)

The same of adult males from Bronze Age western Mongolia had a higher frequency (p=0.0377) of cranial trauma than the sample of western Xiongnu males. There were no significant differences between BW and XW females or BW and XW adults. When compared against the BW and BE samples pooled, the Bronze Age sample still had a higher rate of cranial trauma among males (p=0.0436) then the XW males.

7.5.4.2. Bronze Age East (BE) vs. Xiongnu East (XE)

The Bronze Age and Xiongnu samples from eastern Mongolia had no significant differences in any category of pathological markers among men, women, or all adults. XE males had higher rates of post-cranial trauma (p=0.1875) and DJD U (p=0.1875), and XE females had a higher rate of CT (p=0.1664) than their counterparts in the pooled (BE and BW) Bronze Age sample, but not significantly so.

7.5.4.3. Bronze Age (BA) vs. Xiongnu Central (XC)

In this comparison, I pooled the BW and BE samples to form one Bronze Age group (BA) and compared them to the XC group. The frequency of cranial trauma was higher in the BA males group (p=0.0178) than the XC males group. There were no significant differences between the B and XC female groups, but XC females had a somewhat higher rate of dental caries (p=0.1713) than B females. Among all adults, the Bronze Age sample had a higher frequency of CT (p=0.0749) that the XC sample.

7.5.4.4. Bronze Age (BA) vs. Xiongnu (X)

I then pooled the Xiongnu regional samples (XW, XC, and XE) into one Xiongnu sample (X) and compared them against the pooled (BW and BE) Bronze Age sample (BA).

7.5.4.5. Bronze Age Males vs. Xiongnu Males

Bronze Age males had a higher incidence of cranial trauma than Xiongnu males (p=0.0067).

7.5.4.6. Bronze Age Females vs. Xiongnu Females

Xiongnu females had a higher rate of dental caries than Bronze Age females, but not at the level of statistical significance (p=0.1883). There were no other notable differences between the Xiongnu female and Bronze Age female samples.

7.5.4.7. Bronze Age Adults vs. Xiongnu Adults

Bronze Age adults had higher rate of CT (p=0.0967) than Xiongnu adults.

7.5.4.8. Bronze Age Subadults vs. Xiongnu Subadults

There were no statistically significant differences between Bronze Age and Xiongnu subadults.

7.5.5. Xiongnu vs. Han

7.5.5.1. Xiongnu Males vs. Han Males

I compared the Han males to each of the three Xiongnu regional samples (XW, XC, and XE). XW and XC had higher rates of TMJ (p=0.0992 and p=0.1190 respectively) than their male Han counterparts. XW and XC also had statistically significantly (p=0.0671 and p=0.0049) higher rates of PH than Han males. There was a somewhat higher frequency of post-cranial trauma in the XE males (p=0.1449) than Han males. DJD U was more prevalent in Han males (p=0.1330) than XC males.

When Han males were compared to the pooled Xiongnu sample comprised of the XW, XC, and XE groups, Xiongnu males were found to have significantly higher (p=0.0247) rates of TMJ than Han males. The Xiongnu males also had a higher frequency of PH (p=0.0069). Han males had a higher incidence of DJD U (p=0.0975) than Xiongnu males.

7.5.5.2. Xiongnu Females vs. Han Females

Rates of TMJ were higher in females from all three Xiongnu regional groups than in Han females (XW p=0.1187; XC p=0.0717; XE p=0.1543). The rate of PH was significantly higher in XC (p=0.0010) and XE (p=0.0980) females than females in the Han sample. CT was higher in the XE female sample (p=0.0116) than in Han females, but was not significantly different from the XW and XC female groups.

When the three regional groups (XW, XC, and XE) were pooled, Xiongnu females had higher frequency of TMJ (p=0.0150), PH (p=0.0009) and CT (p=0.0951).

7.5.5.3. Xiongnu Adults vs. Han Adults

I pooled male, female, and indeterminate adult individuals into a sample and compared the Han adults to each Xiongnu regional group. The XW adults had a higher rate of AMTL than Han adults, but not statistically significant (p=0.1444). All three Xiongnu groups, XW, XC, and XE had significantly higher rates of TMJ than Han adults (p=0.0099, 0.0011, and 0.0909 respectively). The XW and XC samples had higher frequencies of PH (p=0.0160 and <0.0001) than adults in the Han sample. Rates of CT were higher in the XE (p=0.0113) and XC (p=0.1167, not statistically significant) groups. The Han adults displayed higher rates of DJD U (p=0.0557) than adults in the XC group.

When compared to all Xiongnu adults as a whole, the Han adults had higher rates of DJD U and DJD L (p=0.0882 and p=0.1801). The Xiongnu adults had higher rates of TMJ (p<0.0001), PH (p<0.0001), and CT (p=0.0466).

7.5.5.4. Xiongnu Subadults vs. Han Subadults

There were no statistically significant differences between Xiongnu and Han subadults.

7.5.6. Bronze Age vs. Han

7.5.6.1. Bronze Age Males vs. Han Males

When comparing the Han sample to the Bronze Age regional groups (BW and BE), the BW males had rates of PH (p=0.0607) and CT (p=0.0002) that were statistically significantly higher than the Han males. The Han males had a higher rate of DJD U, but not quite at the level of statistical significance (p=0.1072).

When the two regional Bronze Age groups were pooled (BW and BE), Bronze Age males had a significantly higher rates of PH (p=0.0731) and CT (p=0.0003) than Han males. Han males had a higher rate of DJD U (p=0.0571) than Bronze Age males.

7.5.6.2. Bronze Age Females vs. Han Females

Between BW and Han females, the BW sample had higher rates of TMJ (p=0.0064), PH (p=0.0001), and CT (p=0.0889). The BE sample had higher rates of TMJ and PH, but not at a level or statistical significance (p=0.1187 and 0.1440), but the rate of PCT was significantly higher (p=0.0980) than in Han females.

When pooled together (BW and BE), Bronze Age females had higher rates of TMJ and PH than Han females, at the level of statistical significance (p=0.0025 and p=0.0005 respectively). Though not statistically significant, Bronze Age females had higher rates of AMTL (p=0.1951) and CT (p=0.1391), and Han females had a higher rate of dental caries (p=0.1771)

7.5.6.3. Bronze Age Adults vs. Han Adults

Adults from BW and BE had higher rates of TMJ (p= 0.0114 and 0.1576) of TMJ than their Han counterparts. The BW group also had a higher frequency of PH (p=0.0001) and CT (p=0.0189) than Han adults. The BE adults had a higher rate of PCT, but not at a level of statistical significance (p=0.1782). The Han adult sample had a rate of DJD U that was statistically higher (p=0.0189) that the BW adult sample. The rate of DJD L was also higher, but not quite statistically significantly so (p=0.1461).

The pooled sample of Bronze Age adults (BW and BE) had significantly higher rates of TMJ (p=0.0054), PH (p<0.0001), and CT (p=0.0001) than the Han adult sample. They also had a higher rate of AMTL, but not statistically significant (p=0.1838). Han adults had a significantly higher rate of DJD U (p=0.0064) that Bronze Age adults.

7.6. Biodistance Analysis

7.6.1. Introduction

The summary statistics of the craniometric variables and the result of the R Matrix analysis are discussed here. My sample for the R Matrix analysis consisted of 157 individuals. I ran the analysis using each regional group as a population, and then with males and females from the same region as separate populations. Sixteen craniometric variables were chosen that account for overall craniofacial shape, as discussed in Chapter 6.

The biodistance analysis was performed using craniometric data. The number of individuals examined that yielded sufficient craniometric data is smaller than the total number of individuals studied here. Because of several factors, including post-depositional damage, warping, and missing cranial elements, I was only able to collect craniometric data from a total of 157 individuals. Figure 7.3 below shows the total number of individuals in each of the grouped samples described above. The Bronze Age East sample only had one individual who yielded craniometric data. One individual is not sufficient for comparison, so the biodistance study only includes one Bronze Age group, Bronze Age West.

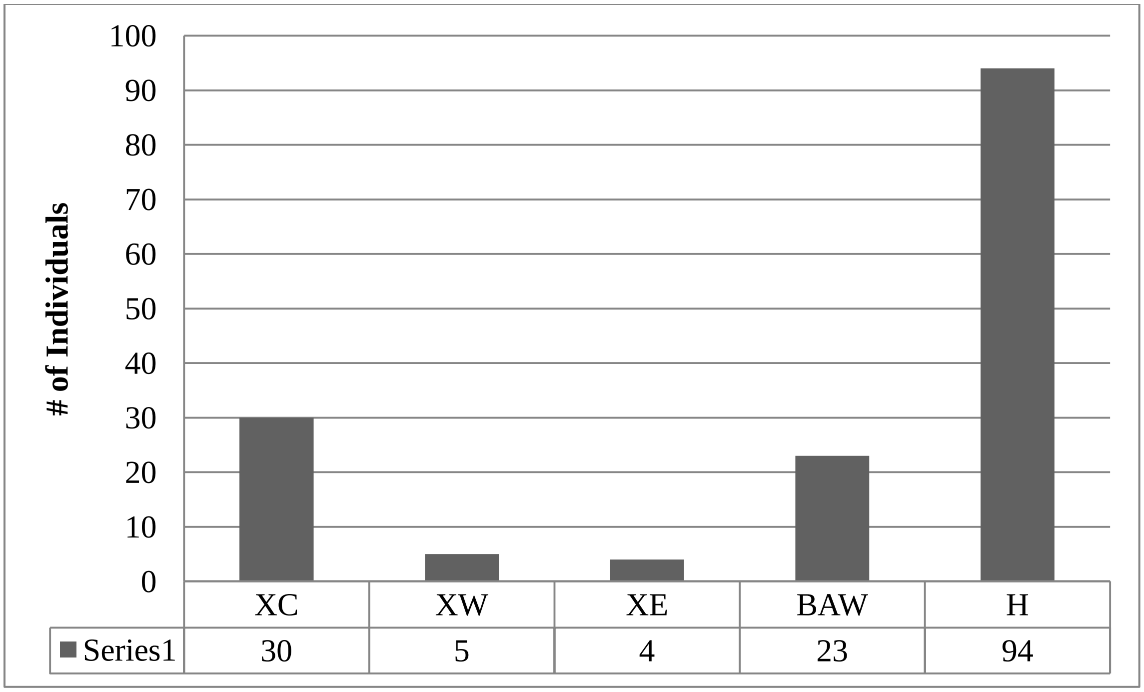


Figure 7.3. Number of individuals in biodistance analysis populations by time period/region.

7.6.2. Summary Statistics

As recommended by various bioanthropological studies, the vector means and variance-covariance matrices of the craniometric variables of each population used in this analysis should be provided so that the results can be reproduced or used to test other hypotheses (Konigsberg 1991; Konigsberg et al. 1998; Uhl et al. 2013). Alternatively, the raw craniometric data, including imputed values, for each individual in this study is provided in Appendix B, Table B.1 to supplement future research or to validate results.

7.6.3. R Matrix Results

The F_{ST} estimate is the proportion of the total genetic variance contained in a subpopulation relative to the total genetic variance, with values ranging from 0 to 1. A high F_{ST} estimate implies a considerable degree of differentiation among the populations, whereas low F_{ST} estimates are likely the result of considerable gene flow between groups. Table 7.10 shows the unbiased F_{ST} estimates for various combinations of population groupings analyzed in this study. All analyses were performed using a heritability estimate (h^2) of 0.55.

The F_{ST} estimate of 0.000 for the Bronze Age and Xiongnu groups, both combined and separated into populations by sex, suggests there was extensive gene flow among these groups. The comparisons among the Xiongnu period regional sites also produced low F_{ST} values, probably the result of genetic exchange among them. The inclusion of the Han population produced the highest F_{ST} estimates, which we would expect given the geographic and presumably genetic separation of the Han population from the nomadic Bronze Age and Xiongnu period populations.

Table 7.10. F_{ST} estimates for populations analyzed in this study.

Population or Region	F_{ST}
All regional groups (BAW, XW, XC, XE, H)	0.033
Bronze Age and Xiongnu groups (BAW, XW, XC, XE)	0.000
Xiongnu groups only (XW, XC, XE)	0.004
All regional groups by sex (BWF, BWM, XWF, XWM, XCF, XCM, XEF, HF, HM)	0.137
Bronze Age and Xiongnu groups by sex (BWF, BWM, XWF, XWM, XCF, XCM, XEF)	0.000
Xiongnu groups by sex (XWF, XWM, XCF, XCM, XEF)	0.003

The biological distances between all regional populations and regional populations separated by sex are presented in Tables 7.11 and 7.12 respectively.

Population size information is unavailable for these groups, so results were calculated with all populations given equal weight.

Table 7.11. Biological distance between regional populations. Standard error is above the diagonal, biological distance is below.

	BAW	XW	XC	XE	H
BAW	--	0.012287	0.006294	0.015486	0.014849
XW	0.012823	--	0.011858	0.028122	0.031639
XC	0.010462	0.012055	--	0.014661	0.013053
XE	-0.008290	-0.015963	-0.006997	--	0.035550
H	-0.032580	-0.047007	-0.033263	-0.05663	--

Table 7.12. Biological distance between populations by sex. Standard error is above the diagonal, biological distance is below.

	BWF	BWM	XWF	XWM	XCF	XCM	XEF	HF	HM
BWF	--	0.013	0.019	0.029	0.012	0.009	0.021	0.051	0.011
BWM	0.010	--	0.018	0.029	0.012	0.009	0.021	0.056	0.012
XWF	0.013	0.015	--	0.040	0.019	0.012	0.027	0.102	0.021
XWM	0.011	0.023	0.013	--	0.028	0.021	0.048	0.125	0.028
XCF	0.012	0.007	0.014	0.007	--	0.009	0.021	0.049	0.011
XCM	0.011	0.011	0.015	0.009	0.012	--	0.015	0.044	0.010
XEF	0.006	0.004	0.014	0.002	0.013	0.012	--	0.102	0.022
HF	-0.116	-0.123	-0.125	-0.258	-0.123	-0.104	-0.152	--	0.031
HM	0.016	0.020	0.024	0.028	0.020	0.019	0.034	-0.209	--

These biological distances are visualized in Figures 7.4 and 7.5, which show the plots of the first two eigenvectors derived for the biological distance matrices. For the populations divided by region, the first eigenvector accounts for 89.9% of the total variation and primarily separates the Han population from the nomadic Bronze Age and Xiongnu populations. The second eigenvector accounts for the remaining 10.1% of variation and separates the nomadic groups from east to west.

Figure 7.4. Principal coordinate plot of first and second eigenvectors of biological distance for regional groups.

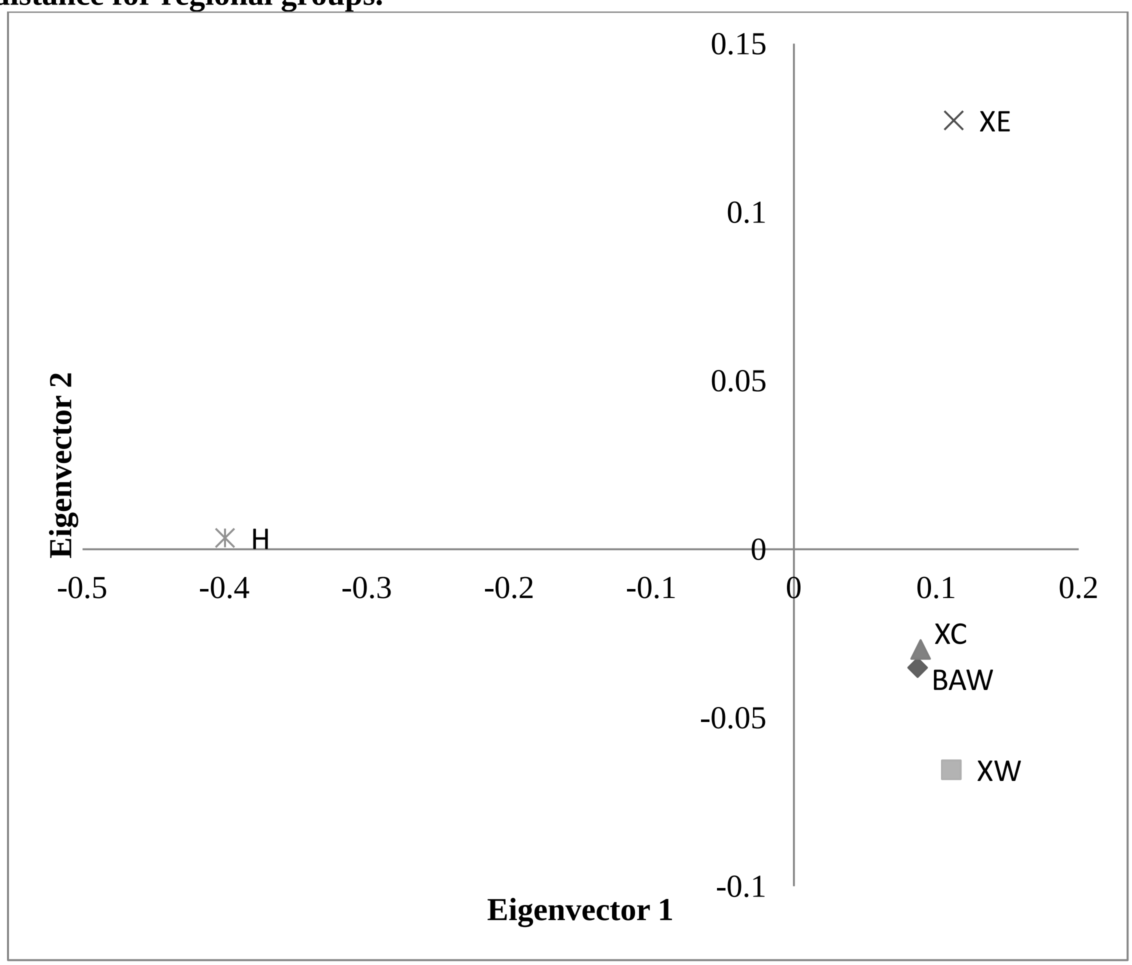
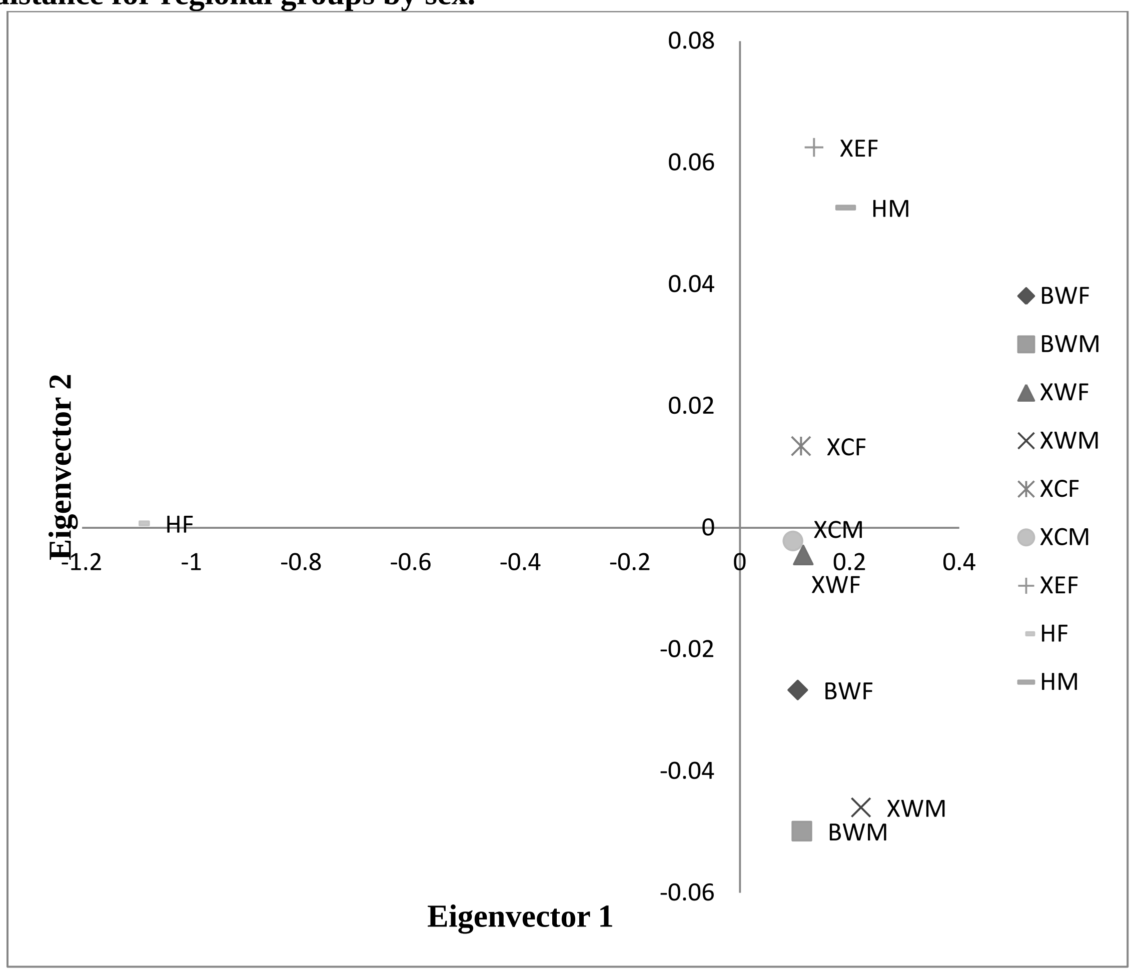


Figure 7.5 shows the plot of the first and second eigenvectors for the regional groups by sex. The first eigenvector accounts for 99.1% of the variation and separates the Han females from the other populations. The second eigenvector accounts for only 0.9% of the variation among these groups and generally separates the groups geographically from east to west, with the exception of the Han male population which falls near the Xiongnu east female group.

Figure 7.5. Principal coordinates plot of first and second eigenvectors of biological distance for regional groups by sex.



The Relethford-Blangero residuals for all regional populations, pooled and by sex, are shown in Tables 7.13 and 7.14 respectively. These results indicate that the Xiongnu West and Xiongnu Central groups were experiencing less than average levels of gene flow. The Han population had the highest rates of gene flow.

Table 7.13. Relethford-Blangero residuals for all regional populations (h^2 = 0.55, F_{ST} = 0.066157, se = 0.011548).

Population	r(ii)	Observed	Expected	Residual
BAW	0.000	0.925	0.917	0.008
XW	0.000	0.537	0.917	-0.379
XC	0.001	0.886	0.916	-0.03
XE	0.000	1.008	0.917	0.092
H	0.164	1.076	0.766	0.309

When we observe the Relethford-Blangero residuals for the populations separated by sex, we see that all of the nomadic male populations (Bronze Age West, Xiongnu West, and Xiongnu Central) are all experiencing less than average rates of gene flow. The Bronze Age West and Xiongnu Central female populations show higher than average levels of gene flow, while Xiongnu West and Xiongnu East females are below average. Both Han male and female populations show higher than average rates of gene flow. These results provide some sense of the pattern of migration among these populations during the Bronze Age and Xiongnu periods.

Table 7.14. Relethford-Blangero residuals for all regional populations by sex (h^2 = 0.55, F_{ST} = 0.137165, se = 0.011074).

Population	r(ii)	Observed	Expected	Residual
BWF	0.000	1.210	1.044	0.166
BWM	0.000	0.734	1.044	-0.309
XWF	0.000	0.775	1.044	-0.269
XWM	0.000	0.619	1.044	-0.425
XCF	0.000	1.198	1.044	0.154
XCM	0.000	0.802	1.044	-0.242
XEF	0.000	0.741	1.044	-0.303
HF	1.200	0.987	-0.209	1.196
HM	0.034	1.039	1.008	0.031

Chapter 8. Discussion

8.1. Introduction

In this study several categories of bioarchaeological data were analyzed to measure the potential dietary, health, and demographic changes associated with the creation of the Xiongnu nomadic empire. The goals of this project were to test the models of nomadic empire formation by examining whether access to Chinese goods, especially agricultural products, significantly changed the dietary composition of Xiongnu people. The health impact of the Xiongnu Empire was also assessed through the observation of several skeletal stress markers. Finally, craniometric data were used to assess biological relatedness among nomadic groups to look for patterns in the migration of people under Xiongnu rule. In this chapter, the results of the analyses presented in Chapter 7 are discussed with respect to the research hypotheses laid out in Chapter 3, and some possible interpretations of these results are provided.

8.2. Dietary Composition

The following sections will compare the rates of skeletal markers that reflect diet (antemortem tooth loss, caries, and TMJ) among the various groups in this study and provide some possible interpretations for these results.

8.2.1. Bronze Age vs. Xiongnu

Rates of antemortem tooth loss were lower in the Xiongnu Central male and female groups than observed in the Bronze Age groups, but higher in the male and female Xiongnu West and Xiongnu East groups.

The frequency of dental caries is lower for all Xiongnu males than Bronze Age males. This is contrary to expectations, if we assume that securing access to cultigens was a major factor in unifying the nomadic tribes. One possible interpretation of this trend, as discussed in Chapter 3, is that the agricultural products received or acquired by the Xiongnu were distributed amongst the elites or as gifts to allies. In this scenario, we would not expect the dietary composition of the majority of the Xiongnu population to differ significantly from the diet of their Bronze Age predecessors.

The rate of dental caries in Xiongnu Central females, however, was higher than that of any other group including Xiongnu Central males. This pattern may indicate that Xiongnu males and females had access to different foods based on their status and activities in which they participated. It has been documented that nomadic pastoralist males tend to the grazing animals while women were more involved in collecting milk from animals. This may have given females greater access to milk products in their diet which could account for the higher rate of caries.

Temporomandibular joint disease (TMJ) was higher in all male and female Xiongnu groups than Bronze Age groups, except the Xiongnu Central female group.

Higher rates of TMJ disease may be the result of using teeth and jaws as tools during activities, and regional or temporal differences in food preparation techniques.

8.2.2. Xiongnu vs. Han

Rates of antemortem tooth loss were similar among Xiongnu Central and Han males and females. The frequency of dental caries is lower for all Xiongnu males than Han males. As discussed in the previous section, his is contrary to expectations. The trends seen in this study could indicate that even though grains made up a larger proportion of the Xiongnu diet than they did during the Bronze Age, it did not reach the level of dependence on grain as we see in the Han diet. These patterns could also indicate that any increased access to cereal grains was not available to all segments of Xiongnu society. The individuals included in the sample for this study may represent non-elite members of Xiongnu society, particularly in central Mongolia.

Rates of dental caries were higher among female Xiongnu groups than Han females. The access to milk products as a significant contribution to diet may account for this pattern.

Rates of TMJ disease were higher among all male and female Xiongnu groups than the Han Dynasty sample. Agricultural diets consist of more processed and softer foods than that of nomadic pastoralists, so we would expect to see higher rates in TMJ disease among the Xiongnu groups. This pattern does suggest that the diet of the Xiongnu people was not as similar to the Han diet in the level of processed grain products it incorporated.

8.2.3. Regional and Sexual Variation within Xiongnu Groups

Rates of antemortem tooth loss were high across all Xiongnu groups. Xiongnu males had consistently higher rates of antemortem tooth loss than Xiongnu women, and the males and females of the Xiongnu Central group had rates of antemortem tooth loss lower than the Xiongnu West or East groups. Rates of dental caries were higher in all the female Xiongnu groups, but there is no clear regional pattern to the incidence of caries. Rates of TMJ disease were similar between Xiongnu males and females, but were lower in the Xiongnu Central group.

The Xiongnu Central individuals may have had access to food resources that caused less wear or damage to the teeth, less mechanical strain on the TMJ resulting in fewer teeth lost and development of TMJ disease during life. If the majority of goods from China coming in to the Xiongnu Empire were going to central Mongolia, it is reasonable that the individuals in that area would have lower rates of antemortem tooth loss and TMJ. The Xiongnu Central males and females had the lowest rates of TMJ disease, closest to the Han sample, which suggests that the people in central Mongolia were incorporating more processed foodstuffs into their diets than individuals on the peripheries of the Xiongnu Empire.

8.2.4. Conclusions

The patterns in dietary indicators seen in this sample of Bronze Age, Xiongnu, and Han individuals present a complex picture of the changes in dietary composition during the Xiongnu period. The lack of significant differences between dietary indicators of Bronze Age and Xiongnu period individuals suggests that the Xiongnu diet did not substantially change, at least for the majority of Xiongnu people. The amount of processed grains in the Xiongnu diet did not approach the level of these foods in the diet of the sedentary agriculturalist Han population. Xiongnu males and females likely had differential access to resources that resulted in different frequencies of dental disease.

8.3. Health Status

This section will discuss the frequencies of indicators of nutritional stress and disease in the study groups, and propose some possible interpretations for these results.

8.3.1. Bronze Age vs. Xiongnu

Overall, Xiongnu adults had slightly higher rates of enamel hypoplasia than Bronze Age adults. Rates of enamel hypoplasia increased for males in the west from the Bronze to Xiongnu periods, but decreased for females. They also decreased for females in the east from the Bronze Age to the Xiongnu period.

The rate of porotic hyperostosis in Xiongnu adults was slightly higher than in the Bronze Age. Bronze Age females had a higher rate of porotic hyperostosis than Xiongnu females, where Bronze Age males had a lower rate of porotic hyperostosis than Xiongnu males. Overall, occurrences of osteoperiostitis were rare in all Bronze Age and Xiongnu groups. The rate of osteoperiostitis was slightly higher in males during the Xiongnu period, but not significantly so.

These results indicate that disease loads for Bronze Age and Xiongnu individuals did not change significantly and remained quite low. Xiongnu adults from all regions appear to have experienced more instances of nutritional inadequacy that resulted in developmental disruption, as seen by the higher rates of enamel hypoplasia and porotic hyperostosis, than Bronze Age adults.

8.3.2. Xiongnu vs. Han

Han males had a higher rate of enamel hypoplasia than Xiongnu males, whereas Han and Xiongnu females had similar rates. Porotic hyperostosis rates were higher in Xiongnu males and females. Xiongnu males had a higher rate of osteoperiostitis than Han males. Osteoperiostitis was rare in both Xiongnu and Han female groups, but one instance was observed in the Han female sample. Han adults were slightly more likely to have experienced malnutrition that resulted in developmental disruption (enamel hypoplasia).

8.3.3. Regional and Sexual Variation within Xiongnu Groups

Among the Xiongnu regional groups, Xiongnu Central males had the lowest rate of enamel hypoplasia and Xiongnu Central females had the highest. Rates of porotic hyperostosis were similar between Xiongnu West and Xiongnu Central males. No instances of porotic hyperostosis in the Xiongnu East sample were observed. In females, rates of porotic hyperostosis were highest among the Xiongnu Central group. Osteoperiostitis was only observed in the Xiongnu Central male group, and no instances of osteoperiostitis were observed in any of the female Xiongnu individuals.

8.3.4. Conclusions

Disease loads of individuals in sedentary communities are typically higher than those of nomadic populations because increased risk factors such as closer proximity to people, waste, and refuse that may harbor disease. Nomadic pastoralists generally have very low disease loads because they move from place to place, and do not remain in confined areas where disease vectors flourish. Both pastoral nomads and sedentary agriculturalists would come in close contact with animals that may spread diseases to humans, but the risk of this occurring should be relatively similar for both groups.

8.4. Interpersonal Violence and Activity Patterns

This section will discuss the changes in rates of interpersonal violence and the different patterns of activity markers among the research groups and offer interpretations for these observations.

8.4.1. Bronze Age vs. Xiongnu

Bronze Age adults had a higher rate of cranial trauma than Xiongnu adults (especially males), and a lower rate of post-cranial trauma. There were no instances of degenerative disease of the upper or lower joints in the Bronze Age male sample, but rates of degenerative disease (upper and lower) were higher in Bronze Age females than Xiongnu.

This pattern aligns with the expected results. If the confederation of tribes under the control of the Xiongnu allowed them access to Chinese cultigens, textiles, and other goods that were previously acquired by raiding during the Bronze Age, we would expect the number of violent interactions between the nomadic pastoralists and the Han subjects to decrease. In addition, the alliance of tribes across the Mongolian steppe under the Xiongnu imperial structure may have also decreased incidents of inter- and intra-tribal violence.

8.4.2. Xiongnu vs. Han

Xiongnu adults had higher rates of cranial and post-cranial trauma than Han adults. This difference was more pronounced between the male samples. This could be explained by more frequent occurrences of raiding/warring activities among the Xiongnu, as well as a larger proportion of the Xiongnu population taking part in these activities. Xiongnu males may also have been predisposed to more accidents that result in trauma because of their nomadic pastoral lifestyle.

The Han adult sample had higher rates of degenerative disease in both upper and lower joints than their Xiongnu counterparts. Han males more frequently displayed degenerative disease in upper and lower joints than Han females. Xiongnu females had very low rates of degenerative joint disease. These patterns likely reflect different activities related to subsistence mode and division of labor between the sexes among the Xiongnu (nomadic pastoral) and the Han (agricultural) samples.

8.4.3. Regional and Sexual Variation within Xiongnu Groups

Among the Xiongnu adults, the western sample had no observed instances of cranial or post-cranial trauma, or degenerative disease of the upper or lower joints. The Xiongnu Central group had lower rates of trauma than Xiongnu East. Degenerative disease of the upper joints was highest in the eastern group, and in the central group for lower joints. Females in all regions had very low rates of trauma and degenerative joint disease.

Violent encounters with groups along the eastern periphery of the Xiongnu Empire may account for the higher rates of trauma in the Xiongnu East sample. Trade agreements or alliances with central Asian societies may account for the low rates of violent trauma among the western Xiongnu people. Differences in rates of degenerative joint disease can be interpreted as reflective of different activities, probably subsistence related, that people in various regions of the Xiongnu Empire participated in.

8.4.4. Conclusions

The stability afforded by the Xiongnu imperial structure appears to have decreased the frequency of violent encounters, based on the relatively lower rates of cranial trauma seen in Xiongnu adults. Shifts in activity patterns from the Bronze Age to the Xiongnu period may account for the differing levels of degenerative joint disease among these groups. The agricultural subsistence mode of the Han sample and the protection provided by the Han Empire account for the low prevalence of violent trauma, as well as the much higher rates of degenerative disease in both males and females.

8.5. Population Structure and Migration

This section will present some interpretations of the results from the R Matrix, biological distance, and Relethford-Blangero residuals analyses.

8.5.1. Bronze Age vs. Xiongnu

There is considerable similarity between the Bronze Age and Xiongnu populations. The Bronze Age population has the closest biological distance to the Xiongnu Central population. Regionally, the Bronze Age West males and Xiongnu west males are most closely related to each other, and both populations appear to have had less genetic exchange than expected. The Bronze Age population of Mongolia is genetically very similar to the Xiongnu population and it appears that interaction and exchange of genetic information among these groups continues from the Bronze Age through the Xiongnu period.

8.5.2. Xiongnu vs. Han

The Han population from Taojiazhai is biologically the most separated from the Xiongnu and Bronze Age samples. This is a logical result, given the Han sample is both geographically and culturally different from the Bronze Age and Xiongnu groups. When the Han population is split into male and female components, the female group remains far removed from the other regional groups, but the Han male population falls very near to the Xiongnu East female sample. The sample size of the Xiongnu East female group is small (n = 3) so the strength of this association is somewhat diminished, but it is possible that ethnically Han females were being relocated to Mongolia as part of the "marriage alliance" treaty with the Xiongnu.

8.5.3. Regional and Sexual Variation within Xiongnu Groups

The Xiongnu regional groups are biologically very similar to one another, but are separated along a geographic gradient. That is, the Xiongnu West and Xiongnu East groups are biologically furthest from each other, with the Xiongnu Central population falling in between them. This pattern is what we would expect, as it reflects the geographic distances between the groups. The western and central Xiongnu groups display less than average levels intra-group variation, which indicates less external gene flow. This could be the results of outside, populations being incorporated into the Xiongnu East gene pool.

The Xiongnu West female group has the closest biological affinity to the Xiongnu Central male group. One explanation for this pattern is the relocation of females from the elite Xiongnu lineage to peripheral areas of the empire to secure the loyalty of local tribal leaders through marriage alliances.

8.5.4. Conclusions

The Bronze Age and Xiongnu populations are biologically very similar to one another, likely because of regular interaction and exchange of genetic material among them. There is some evidence that females (possibly elites) from central Mongolia were relocated throughout the empire to secure the allegiance of local tribal leaders. Females from the Chinese Han Empire may have been sent to Mongolia to reinforce the *heqin* (marriage alliance) treaty between them.

8.6. Summary

This chapter has discussed at greater length the results presented in Chapter 7 and their significance with regard to the research goals of this study. The interpretations presented here improve our understanding of the regional variations among the Xiongnu population, as well as the differences between the Xiongnu, their Bronze Age predecessors, and their Han neighbors. These data also provide health profile information that correlate dietary composition, health, and activity patterns with subsistence strategies, sex, and social structure. The following chapter will summarize these findings and address their implications, as well provide some suggestions for avenues of further research.

Chapter 9. Conclusion

9.1. Introduction

This dissertation has explored the ways in which the creation of the Xiongnu Empire impacted the diet, health, activity patterns, and demographics of the nomadic tribes under its control. This study provides a bioarchaeological angle to supplement previous work predominantly based on textual and archaeological sources.

I used multiple lines of bioarchaeological data from 349 individuals from 27 separate cemetery sites. These sites were mainly located across the Mongolian steppe, with the inclusion of one site in northwestern China. Pooling data from these sites into groups at increasingly broad levels allowed the identified of differences in health and biological affinity with regard to subsistence method, region, sex, and time period. Chapter 7 presented the results of the analyses, which were discussed further in Chapter 8. This chapter will summarize the results of this study and discuss the contribution of this research to Xiongnu and empire studies, as well as suggest some areas for further research.

9.2. Testing Research Hypotheses

The results of this study indicate that Bronze Age adults had the best overall health status, based on lowest frequency of health indicators in the most categories, when compared to all other groups. Han adults were also healthier than Xiongnu adults, leaving the Xiongnu sample with the poorest overall health profile. This same pattern held when comparing just the males in the sample. Bronze Age and Han males were both healthier than Xiongnu males. The trend does not hold when observing the female sample. Han females had the best overall health profile. Xiongnu females were healthier than Bronze Age females, who had the poorest overall health profile.

These patterns indicate that, broadly speaking, the Xiongnu Empire did not improve health status for most of its subjects, as compared to their Bronze Age predecessors. The following sections will summarize the findings with respect to the bioarchaeological hypotheses set forth for this study.

9.2.1. Impact of the Xiongnu Empire on Diet

The amount of cereal products in the diet does seem to increase during the Xiongnu period, as seen by an increase in the rate of dental caries and decrease in the rate of antemortem tooth loss over the Bronze Age sample. The frequency of dental caries and TMJ disease increased during the Xiongnu period across all regions. Antemortem tooth loss increased in the eastern and western samples, but decreased in the central Xiongnu group. These dietary indicators do not reach the frequency seen in the Han agricultural sample from Taojiazhai.

Grain as a component of the diet may have increased more for females than males. Antemortem tooth loss decreased, dental caries increased, and TMJ disease decreased for Xiongnu females, whereas males have a decrease in antemortem tooth loss, but also a decrease in the frequency of dental caries. The dental health pattern for females is similar to what we would expect to see in an agricultural sample; the pattern for males is more reflective of the typical nomadic pastoral diet. These results suggest that treaties and trade between the Xiongnu and China, and likely with sedentary societies in central Asia, did increase access to and availability of agricultural products for the Xiongnu population.

9.2.2. Impact of the Xiongnu Empire on Health

Enamel hypoplasias, porotic hyperostosis, and osteoperiostitis are all skeletal markers that correlate to nutritional stress and disease loads. The Xiongnu adult population exhibits higher rates in all three categories than their Bronze Age counterparts. Episodes of malnutrition or infectious disease were more prevalent during the Xiongnu period, however did not occur as frequently in the Xiongnu group as they did in the Han adult sample.

Rates of enamel hypoplasia increased in the Xiongnu sample from west to east. Xiongnu females appear to have experienced nutritional stress during childhood more often than males, as the frequency of enamel hypoplasia was higher than in males. Rates of osteoperiostitis were low in all Xiongnu groups, suggesting that infectious disease risks were minimal. Overall, the societal and dietary changes taking place during the Xiongnu period do appear to have resulted in a decline in health and more instances of developmental disruption caused by malnutrition and disease.

9.2.3. Impact of the Xiongnu Empire on Interpersonal Violence

Frequency of cranial trauma decreased in Xiongnu adults from the levels seen in adults during the Bronze Age. Rates of post-cranial and cranial trauma stayed relatively the same for Bronze Age and Xiongnu females, but cranial trauma decreased significantly in Xiongnu males. Regionally, rates of trauma increased from west to east among the Xiongnu sample. Xiongnu males had a higher rate of cranial trauma, but lower rate of post-cranial trauma than Xiongnu females. The Xiongnu adult sample had higher rates of cranial and post-cranial trauma than their Han counterparts.

The protection afforded by the Xiongnu alliance appears to have reduced the amount of violent trauma during this period. Trade and tribute agreements may have reduced the amount of raiding activity that took place to acquire resources. The unification of the nomadic tribes may also have decreased inter-tribal conflicts that could have led to violent encounters.

9.2.4. Impact of the Xiongnu Empire on Population Structure

The small biological distances among the Bronze Age and Xiongnu populations attest to the extensive flow of genetic material between them. The Xiongnu Central population is biologically closest to the Bronze Age West group, even more so than the Xiongnu West sample. The Xiongnu West female sample is biologically closest to the Xiongnu Central males. There is not much change between males in western Mongolia from the Bronze Age to the Xiongnu period, so the genetic exchange is likely occurring through the influx of females from other areas. One possible interpretation of this result is that females from the elite Xiongnu lineage in central Mongolia were sent to the peripheral regions of the empire to secure marriage alliances with local tribal leaders.

The Han sample has the greatest biological distance from the Mongolian groups, which is reasonable based on the geographic and purported genetic separation between them. However, when the biological distance is plotted for each region or time period by sex, the males from the Han sample are closest to the Xiongnu East female sample. These regions are geographically farther from each other than any other in this study, so this result is surprising. The Xiongnu East female sample is very small (n = 3), so this association should be viewed cautiously, but one possible interpretation is that ethnically Han females may have been sent to eastern Mongolia (and perhaps other areas of Mongolia) as part of the *heqin* "marriage alliance," which would account for their apparent genetic affinity.

Collecting craniometric data from Bronze Age sites in central and eastern Mongolia, and expanding the sample of data from western and eastern Mongolia during the Xiongnu period would be extremely useful in interpreting the patterns and relationships among the Bronze Age and Xiongnu regional populations.

9.3. Implications of Results on Xiongnu and Empire Studies

The present research has contributed to the repository of skeletal data from Mongolian Bronze Age and Xiongnu collections. The results from this preliminary research provide information on the biological correlates of nomadic empire formation, which can support future research into the Xiongnu Empire, subsequent nomadic empires in Mongolia, and comparative research on societies worldwide that fit a more traditional definition of “empire.” This study has also created a basic biological profile of health for nomadic groups during the Bronze Age in Mongolia, which can be useful in Bronze Age studies.

This study provides a bioarchaeological perspective on the physical impacts of empire on the lives of the nomadic groups living under its influence. Although the conclusions I was able to draw from these analyses are necessarily broad, they challenge some of the long-held assumptions of nomadic empire formation and bring up interesting questions about the benefit of empires to their populace and the methods by which individuals are compelled to participate in them. The trends seen here point to a complex system of interactions at the local, regional, and imperial level that impact physical health among the Xiongnu population.

The Xiongnu people overall did not enjoy better health as a result of their participation in the empire. Violent interactions did decrease during this time period, but dental health suffered and non-specific health stressors increased.

9.4. Avenues for Further Research

Although this study has revealed some interesting patterns and new information on the biological impacts of the Xiongnu Empire, it also presents many new lines of investigation into nomadic empire formation and implementation. This dissertation drew upon a large collection of data from many archaeological sites across the Mongolian steppe. These data were well suited to the goal of the present study, which was to tease out trends and patterns in health profiles and population structure. To increase the power of these analyses, and thereby the strength of the interpretations based upon them, a larger sample size and better representation of specific regions within the sample are necessary. Central Mongolia contains more ostentatious cemeteries and is the focus of more archaeological survey and excavation than the peripheral regions of western and eastern Mongolia. As research continues in Mongolia, more skeletal material from individuals in these peripheral regions, from the Bronze Age and Xiongnu periods, will become available for study. These new sources of bioarchaeological data will enhance the analyses that can be conducted.

Another impediment to performing detailed examinations of the data I collected was a lack of contextual archaeological information from each site. Data on the burial architecture, grave goods, and burial location relative to others in the cemetery associated with each individual set of skeletal remains would be extremely useful in identifying social status. This would allow comparisons between elite and non-elite individuals, both within and between sites, and would undoubtedly reveal correlations worthy of further research.

The addition of isotopic and DNA research to the types of analyses conducted in this dissertation would allow a more complete investigation of dietary changes and migratory patterns within the Xiongnu Empire. Carbon and nitrogen stable isotope data for the individuals in this sample would complement the dietary indicators recorded here, and allow for a more detailed interpretation of the trends observed in these results.

Carbon/nitrogen ratios would allow us to quantify the contribution of different meats and grains in the diet of Xiongnu people. Similarly, strontium isotope results for these individuals in tandem with the results of the present biological distance study would add insight into the movement of people, which segments of the population are relocating, and the areas they are migrating from. DNA profiles would also strengthen the interpretations of biological distance analyses based on craniometric data. Mitochondrial and Y DNA data would provide information on matrilineal or patrilineal movement of individuals. All of these potential avenues of inquiry would allow us to fine-tune our understanding of how the Xiongnu Empire affected different segments of the population.

Appendix A. Frequency Tables of Health Data

Table A.1. Statistical comparison of health indicators between Bronze Age and Xiongnu adult males by region.

Bronze Age vs Xiongnu Males by Region						
	B-XW		B-XC		B-XE	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	1.0000	No	0.7178	No	1.0000	No
Caries	1.0000	No	0.3173	No	1.0000	No
TMJ	0.5467	No	0.6900	No	0.4231	No
EH	1.0000	No	1.0000	No	0.2949	No
PH	1.0000	No	0.7160	No	1.0000	No
OP	1.0000	No	0.5254	No	1.0000	No
PCT	1.0000	No	0.5254	No	0.1875	No (XE>B)
CT	0.0436	No	0.0178	**Yes (B>XC)**	1.0000	No
DJD U	1.0000	No	0.5254	No	0.1875	No (XE>B)
DJD L	1.0000	No	1.0000	No	1.0000	No

Table A.2. Statistical comparison of health indicators between Han and Xiongnu adult males by region.

Han vs Xiongnu Males by Region						
	H-XW		H-XC		H-XE	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	0.3768	No	1.0000	No	0.4987	No
Caries	1.0000	No	0.3275	No	1.0000	No
TMJ	0.0992	**Yes (XW>H)**	0.1190	No (XC>H)	0.2011	No
EH	1.0000	No	0.2724	No	0.3227	No
PH	0.0671	**Yes (XW>H)**	0.0049	**Yes (XC>H)**	1.0000	No
OP	1.0000	No	0.5745	No	1.0000	No
PCT	1.0000	No	0.5745	No	0.1449	No (XE>H)
CT	1.0000	No	0.4038	No	0.2333	No
DJD U	0.3233	No	0.1330	No (H>XC)	1.0000	No
DJD L	1.0000	No	0.6665	No	1.0000	No

Table A.3. Statistical comparison of health indicators between Bronze Age and Han adult males.

Bronze Age vs Han Males by Region						
	BW-BE		BW-H		BE-H	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	--	--	0.7430	No	--	--
Caries	--	--	1.0000	No	--	--
TMJ	--	--	0.3300	No	--	--
EH	--	--	1.0000	No	--	--
PH	1.0000	No	0.0607	**Yes (BW>H)**	1.0000	No
OP	1.0000	No	1.0000	No	1.0000	No
PCT	1.0000	No	1.0000	No	1.0000	No
CT	0.4615	No	0.0002	**Yes (BW>H)**	1.0000	No
DJD U	1.0000	No	0.1072	No (H>BW)	1.0000	No
DJD L	1.0000	No	0.5809	No	1.0000	No

Table A.4. Statistical comparison of health indicators between Bronze Age and Xiongnu adult females by region.

Bronze Age vs Xiongnu Females by Region						
	B-XW		B-XC		B-XE	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	1.0000	No	0.2057	No	0.6161	No
Caries	0.4887	No	0.1713	No (XC>B)	0.2098	No
TMJ	1.0000	No	0.4324	No	1.0000	No
EH	1.0000	No	0.4179	No	1.0000	No
PH	1.0000	No	0.4651	No	1.0000	No
OP	1.0000	No	1.0000	No	1.0000	No
PCT	1.0000	No	0.4651	No	1.0000	No
CT	1.0000	No	0.5900	No	0.1664	No (B>XE)
DJD U	1.0000	No	0.4651	No	1.0000	No
DJD L	1.0000	No	1.0000	No	1.0000	No

Table A.5. Statistical comparison of health indicators between Han and Xiongnu adult females by region.

Han vs Xiongnu Females by Region						
	H-XW		H-XC		H-XE	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	0.5578	No	0.8054	No	0.2971	No
Caries	1.0000	No	0.8007	No	0.6055	No
TMJ	0.1187	No (XW>H)	0.0717	**Yes (XC>H)**	0.1543	No (XE>H)
EH	1.0000	No	0.5618	No	1.0000	No
PH	1.0000	No	0.0010	**Yes (XC>H)**	0.0980	**Yes (XE>H)**
OP	1.0000	No	1.0000	No	1.0000	No
PCT	1.0000	No	1.0000	No	1.0000	No
CT	1.0000	No	0.4814	No	0.0116	**Yes (XE>H)**
DJD U	1.0000	No	1.0000	No	1.0000	No
DJD L	1.0000	No	1.0000	No	1.0000	No

Table A.6. Statistical comparison of health indicators between all Bronze Age and Han adult females.

Bronze Age and Han Females						
	BW-BE		BW-H		BE-H	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	1.0000	No	0.2717	No	0.5578	No
Caries	1.0000	No	0.3796	No	0.5487	No
TMJ	1.0000	No	0.0064	**Yes (BW>H)**	0.1187	No (BE>H)
EH	0.3137	No	0.4611	No	0.4801	No
PH	0.2663	No	0.0001	**Yes (BW>H)**	1.0000	No
OP	1.0000	No	1.0000	No	1.0000	No
PCT	0.2500	No	1.0000	No	0.0980	No (BE>H)
CT	1.0000	No	0.0889	**Yes (BW>H)**	1.0000	No
DJD U	0.2500	No	1.0000	No	0.1440	
DJD L	0.2500	No	0.5903	No	0.3468	No

Table A.7. Statistical comparison of health indicators between Bronze Age and Xiongnu adults by region.

Bronze Age vs Xiongnu Adults by Region						
	B-XW		B-XC		B-XE	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	0.4477	No	0.3683	No	0.7164	No
Caries	1.0000	No	0.7916	No	0.6603	No
TMJ	0.3780	No	1.0000	No	1.0000	No
EH	1.0000	No	0.7515	No	0.5928	No
PH	1.0000	No	0.6183	No	1.0000	No
OP	1.0000	No	0.4985	No	1.0000	No
PCT	1.0000	No	0.3713	No	0.4188	No
CT	0.3227	No	0.0749	**Yes (B>XC)**	1.0000	No
DJD U	1.0000	No	0.4985	No	0.1342	No (XE>B)
DJD L	1.0000	No	1.0000	No	1.0000	No

Table A.8. Statistical comparison of health indicators between Han and Xiongnu adults by region.

Han vs Xiongnu Adults by Region						
	H-XW		H-XC		H-XE	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	0.1444	No (XW>H)	0.8657	No	0.3030	No
Caries	1.0000	No	0.5781	No	0.7250	No
TMJ	0.0099	**Yes (XW>H)**	0.0011	**Yes (XC>H)**	0.0909	**Yes (XE>H)**
EH	1.0000	No	1.0000	No	0.6615	No
PH	0.0160	**Yes (XW>H)**	<0.0001	**Yes (XC>H)**	0.2416	No
OP	1.0000	No	1.0000	No	1.0000	No
PCT	1.0000	No	0.6135	No	0.2830	No
CT	1.0000	No	0.1167	No (XC>H)	0.0113	**Yes (XE>H)**
DJD U	0.6040	No	0.0557	**Yes (H>XC)**	0.6905	No
DJD L	1.0000	No	0.3852	No	0.6056	No

Table A.9. Statistical comparison of health indicators between Bronze Age and Han adults by region.

Bronze Age and Han Adults						
	BW-BE		BW-H		BAE-H	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	1.0000	No	0.2363	No	0.5874	No
Caries	1.0000	No	0.6598	No	0.5576	No
TMJ	0.5235	No	0.0114	**Yes (BW>H)**	0.1576	No (BE>H)
EH	0.3303	No	0.4232	No	0.4466	No
PH	0.3077	No	<0.0001	**Yes (BW>H)**	1.0000	No
OP	1.0000	No	0.6015	No	1.0000	No
PCT	0.1795	No (E>W)	1.0000	No	0.1782	No (BE>H)
CT	0.1693	No (W>E)	<0.0001	**Yes (BW>H)**	1.0000	No
DJD U	1.0000	No	0.0189	**Yes (H>BW)**	1.0000	No
DJD L	0.1795	No (E>W)	0.1461	No (H>BW)	0.4918	No

Table A.10. Statistical comparison of health indicators between Xiongnu West and Xiongnu Central adults by sex.

Xiongnu West (XW) vs Xiongnu Central (XC)						
	Males		Females		All Adults	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	0.6146	No	0.5331	No	0.2501	No
Caries	0.5043	No	1.0000	No	1.0000	No
TMJ	0.5968	No	0.4368	No	0.3888	No
EH	0.3667	No	1.0000	No	1.0000	No
PH	1.0000	No	1.0000	No	1.0000	No
OP	1.0000	No	1.0000	No	1.0000	No
PCT	1.0000	No	1.0000	No	1.0000	No
CT	1.0000	No	1.0000	No	1.0000	No
DJD U	1.0000	No	1.0000	No	1.0000	No
DJD L	1.0000	No	1.0000	No	1.0000	No

Table A.11. Statistical comparison of health indicators between Xiongnu Central and Xiongnu East adults by sex.

Xiongnu Central (XC) vs Xiongnu East (XE)						
	Males		Females		All Adults	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	0.4935	No	0.2668	No	0.4672	No
Caries	1.0000	No	1.0000	No	0.6810	No
TMJ	0.4805	No	0.5269	No	1.0000	No
EH	0.1775	No (XE>XW)	0.5494	No	0.6352	No
PH	0.5396	No	1.0000	No	0.2679	No
OP	1.0000	No	1.0000	No	1.0000	No
PCT	0.3188	No	1.0000	No	0.5012	No
CT	0.4077	No	0.0733	**Yes (XE>XC)**	0.1412	No (XE>XC)
DJD U	0.3188	No	1.0000	No	0.1806	No (XE>XC)
DJD L	1.0000	No	1.0000	No	1.0000	No

Table A.12. Statistical comparison of health indicators between Xiongnu West and Xiongnu East adults by sex.

Xiongnu West (XW) vs Xiongnu East (XE)						
	Males		Females		All Adults	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	1.0000	No	1.0000	No	1.0000	No
Caries	1.0000	No	1.0000	No	1.0000	No
TMJ	1.0000	No	1.0000	No	0.6199	No
EH	1.0000	No	1.0000	No	1.0000	No
PH	0.5000	No	1.0000	No	0.5368	No
OP	1.0000	No	1.0000	No	1.0000	No
PCT	0.3333	No	1.0000	No	1.0000	No
CT	0.3333	No	0.4643	No	0.2421	No
DJD U	0.3333	No	1.0000	No	0.4947	No
DJD L	1.0000	No	1.0000	No	1.0000	No

Table A.13. Statistical comparison of health indicators between Bronze Age West and Xiongnu West adults by sex.

Bronze Age West (BW) vs Xiongnu West (XW)						
	Males		Females		All Adults	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	1.0000	No	1.0000	No	0.4398	No
Caries	1.0000	No	1.0000	No	1.0000	No
TMJ	0.5467	No	1.0000	No	0.3631	No
EH	1.0000	No	1.0000	No	1.0000	No
PH	1.0000	No	0.5221	No	1.0000	No
OP	1.0000	No	1.0000	No	1.0000	No
PCT	1.0000	No	1.0000	No	1.0000	No
CT	0.0377	No	1.0000	No	0.1620	No
DJD U	1.0000	No	1.0000	No	1.0000	No
DJD L	1.0000	No	1.0000	No	1.0000	No

Table A.14. Statistical comparison of health indicators between Bronze Age East and Xiongnu East adults by sex.

Bronze Age East (BE) vs Xiongnu East (XE)						
	Males		Females		All Adults	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	--	--	1.0000	No	1.0000	No
Caries	--	--	0.4286	No	0.5091	No
TMJ	--	--	1.0000	No	1.0000	No
EH	--	--	0.4286	No	1.0000	No
PH	1.0000	No	1.0000	No	1.0000	No
OP	1.0000	No	1.0000	No	1.0000	No
PCT	1.0000	No	1.0000	No	1.0000	No
CT	1.0000	No	0.4444	No	0.2632	No
DJD U	1.0000	No	1.0000	No	1.0000	No
DJD L	1.0000	No	1.0000	No	0.3684	No

Table A.15. Statistical comparison of health indicators between Bronze Age and Xiongnu Central adults by sex.

Bronze Age (B) vs Xiongnu Central (XC)						
	Males		Females		All Adults	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	0.7178	No	0.2057	No	0.3683	No
Caries	0.3173	No	0.1713	No (XC>B)	0.7916	No
TMJ	1.0000	No	0.4324	No	1.0000	No
EH	1.0000	No	0.4179	No	0.7515	No
PH	0.7160	No	1.0000	No	0.6183	No
OP	0.5254	No	1.0000	No	0.4985	No
PCT	0.5254	No	0.4651	No	1.0000	No
CT	0.0178	**Yes (B>XC)**	0.5900	No	0.0749	**Yes (B>XC)**
DJD U	0.5254	No	0.4651	No	1.0000	No
DJD L	1.0000	No	1.0000	No	1.0000	No

Table A.16. Statistical comparison of health indicators between all Bronze Age and Xiongnu adults by sex.

Bronze Age (B) vs Xiongnu (X)						
	Males		Females		All Adults	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	1.0000	No	0.5468	No	0.8289	No
Caries	0.3287	No	0.1883	No (X>B)	0.8020	No
TMJ	0.6900	No	0.4802	No	0.8036	No
EH	1.0000	No	0.6879	No	0.7644	No
PH	1.0000	No	0.7325	No	1.0000	No
OP	1.0000	No	1.0000	No	0.5305	No
PCT	0.5456	No	0.3922	No	1.0000	No
CT	0.0067	**Yes (B>X)**	1.0000	No	0.0961	**Yes (B>X)**
DJD U	0.5456	No	0.3922	No	0.6497	No
DJD L	1.0000	No	1.0000	No	1.0000	No

Table A.17. Statistical comparison of health indicators between all Xiongnu and Han adults by sex.

Xiongnu (X) vs Han (H)						
	Males		Females		All Adults	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	0.4885	No	0.6640	No	0.2941	No
Caries	0.2414	No	0.6539	No	0.6235	No
TMJ	0.0247	**Yes (X>H)**	0.0150	**Yes (X>H)**	<0.0001	**Yes (X>H)**
EH	0.7421	No	1.0000	No	1.0000	No
PH	0.0069	**Yes (X>H)**	0.0009	**Yes (X>H)**	<0.0001	**Yes (X>H)**
OP	0.6165	No	1.0000	No	1.0000	No
PCT	0.3458	No	1.0000	No	0.4021	No
CT	0.4511	No	0.0951	**Yes (X>H)**	0.0466	**Yes (X>H)**
DJD U	0.0975	**Yes (H>X)**	1.0000	No	0.0882	**Yes (H>X)**
DJD L	0.4142	No	0.6782	No	0.1801	No (H>X)

Table A.18. Statistical comparison of health indicators between all Bronze Age and Han adults by sex.

Bronze Age (B) vs Han (H)						
	Males		Females		All Adults	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	0.7430	No	0.1951	No (B>H)	0.1838	No (B>H)
Caries	1.0000	No	0.1771	No (H>B)	0.4001	No
TMJ	0.3300	No	0.0025	**Yes (B>H)**	0.0054	**Yes (B>H)**
EH	1.0000	No	0.7360	No	0.6092	No
PH	0.0731	**Yes (B>H)**	0.0005	**Yes (B>H)**	>0.0001	**Yes (B>H)**
OP	1.0000	No	1.0000	No	0.6136	No
PCT	1.0000	No	0.3188	No	1.0000	No
CT	0.0003	**Yes (B>H)**	0.1391	No (B>H)	0.0001	**Yes (B>H)**
DJD U	0.0571	**Yes (H>B)**	0.4394	No	0.0064	**Yes (H>B)**
DJD L	0.05849	No	1.0000	No	0.3291	No

Table A.19. Statistical comparison of health indicators between males and females by time period/region.

Males (M) vs Females (F)						
	Bronze Age		Xiongnu		Han	
	p value	Significant?	p value	Significant?	p value	Significant?
AMTL	0.7167	No	0.1799	No (M>F)	0.0606	**Yes (M>F)**
Caries	0.6457	No	0.0286	**Yes (F>M)**	0.2672	No
TMJ	0.6765	No	0.3550	No	0.1432	No (M>F)
EH	1.0000	No	0.7049	No	0.8264	No
PH	1.0000	No	0.5561	No	0.1485	No (M>F)
OP	1.0000	No	0.4921	No	0.5565	No
PCT	1.0000	No	0.2381	No	0.5565	No
CT	0.0135	**Yes (M>F)**	1.0000	No	0.1979	No
DJD U	1.0000	No	0.2381	No	<0.0001	**Yes (M>F)**
DJD L	1.0000	No	1.0000	No	0.5557	No

Table A.20. Statistical comparison of health indicators between adults and subadults by time period/economic mode.

Adults (A) vs. Subadults (SA)						
	Bronze Age		Xiongnu		Han	
	p value	Significant?	p value	Significant?	p value	Significant?
PH	0.5661	No	1.0000	No	0.0458	**Yes (SA>A)**
OP	1.0000	No	1.0000	No	0.0148	**Yes (SA>A)**
PCT	1.0000	No	1.0000	No	0.5615	No
CT	0.5661	No	0.5892	No	0.6002	No

Table A.21. Statistical comparison of health indicators between Bronze Age and Xiongnu subadults by region.

Bronze Age vs Xiongnu Subadults by Region						
	B-XW		B-XC		B-XE	
	p value	Significant?	p value	Significant?	p value	Significant?
PH	1.0000	No	0.4872	No	--	--
OP	1.0000	No	1.0000	No	--	--
PCT	1.0000	No	1.0000	No	--	--
CT	1.0000	No	1.0000	No	--	--

Table A.22. Statistical comparison of health indicators between Han and Xiongnu subadults by region.

Han vs Xiongnu Subadults by Region						
	H-XW		H-XC		H-XE	
	p value	Significant?	p value	Significant?	p value	Significant?
PH	1.0000	No	0.2677	No	--	--
OP	1.0000	No	0.5628	No	--	--
PCT	1.0000	No	1.0000	No	--	--
CT	1.0000	No	1.0000	No	--	--

Appendix B. Craniometric Data

Table B.1. Craniometric Data.

Catalog #	Site	Sex	GOL	XCB	BBH	NPH	ZYB	NLB
AT 059	CU	F	206	124	133	66	117	29
AT 105	CU	F	184	133	131	58	125	23
AT109	CU	F	177	132	123	56	114	21
AT 126	CU	F	187	139	111	67	131	23
AT 127	CU	F	177	154	129	57	137	25
AT 218	US	F	174	138	124	69	127	25
AT 497	KT	F	191	151	123	74	124	27
AT 499	KT	F	171	155	123	54	118	20
AT 610	UU	F	172	151	142	69	136	24
AT 611	UU	F	161	146	121	63	129	23
AT 630	KA	F	169	136	122	61	133	26
AT 635	KA	F	177	132	129	61	131	24
AT 121	CU	I	187	132	124	61	138	26
AT 098	CU	M	178	138	134	68	134	25
AT 100	CU	M	180	141	133	67	133	25
AT 128	CU	M	187	139	136	73	141	24
AT 138	CU	M	189	143	135	66	127	24
AT 140	CU	M	184	150	129	64	134	27
AT 281	CU	M	176	151	124	57	133	23
AT 612	UU	M	182	153	137	69	142	27
AT 613	UU	M	177	145	121	73	139	24
AT 677	UDD	M	181	134	130	63	135	28
AT 712	UU	M	176	144	125	66	140	27
AT 150	SK	F	181	145	134	57	117	22
AT 261	BU	F	166	117	122	61	112	25
AT 268	BU	F	182	136	124	67	130	26
AT 294	BU	F	177	143	125	61	128	28
AT 296	BU	F	173	122	127	62	130	25
AT 314	KGA	F	171	129	126	54	121	26

Catalog #	NLH	OBH	OBB	BNL	BPL	EKB	ZMB	DKB	MAB	MAL
AT 059	56	32	38	108	79	90	85	21	62	54
AT 105	45	30	35	99	97	90	97	21	60	52
AT109	41	31	34	85		86	85	22	56	44
AT 126	51	33	39	98	83	94	94	24	60	46
AT 127	42	31	37	79	89	93	96	27	57	42
AT 218	50	33	39	96	100	95	97	19	63	51
AT 497	53	33	38	103	99	95	107	23	63	58
AT 499	40	36	38	87	72	90	75	18	70	32
AT 610	55	34	39	94	90	91	92	17	59	47
AT 611	50	32	42	92	83	91	92	18	56	44
AT 630	51	33	39	96	88	97	98	25	53	41
AT 635	47	31	34	97	91	91	98	24	59	50
AT 121	48	30	38	97	79	94	109	25	59	48
AT 098	52	32	35	99	93	97	104	27	61	50
AT 100	51	30	41	100	98	99	102	23	64	49
AT 128	52	35	41	105	101	103	97	24	59	47
AT 138	51	29	38	102	93	92	90	21	59	47
AT 140	50	34	37	97	96	96	97	23	60	47
AT 281	44	28	38	94	93	91	89	22	66	43
AT 612	56	37	42	103	91	101	102	26	60	45
AT 613	54	37	41	94	85	94	89	19	58	42
AT 677	53	36	40	103	96	99	97	24	53	51
AT 712	53	34	38	97	97	98	106	20	63	47
AT 150	45	32	35	96	87	90	82	24	57	42
AT 261	48	35	34	81	79	89	89	22	57	42
AT 268	49	34	39	96	98	99	97	26	65	45
AT 294	51	35	39	95	87	99	100	23	63	45
AT 296	47	35	36	92	104	95	98	23	60	42
AT 314	48	31	36	97	82	90	79	14	45	38

Catalog #	Site	Sex	GOL	XCB	BBH	NPH	ZYB	NLB
AT 409	BU	F	166	139	119	59	124	26
AT 537	BT	F	174	135	127	64	132	25
AT 684	TUK	F	175	143	120	61	133	25
AT 745	GM	F	178	130	120	54	135	23
AT 907	BA	F	178	139	132	57	123	22
AT 908	BA	F	162	150	124	56	115	23
AT 909	BA	F	176	138	126	56	127	25
AT 033	TU	I	180	142	130	70	139	29
AT 023	TU	M	189	146	134	80	138	24
AT 035	TU	M	185	149	127	69	132	25
AT 036	TU	M	181	151	160	79	153	34
AT 145	TU	M	183	151	129	78	141	28
AT 146	TU	M	188	150	131	74	146	27
AT 164	NU	M	178	146	129	72	135	24
AT 259	BU	M	175	150	118	66	134	29
AT 260	BU	M	190	165	126	71	156	27
AT 292	BU	M	196	160	127	72	147	28
AT 293	BU	M	181	152	119	67	141	21
AT 539	ET	M	191	148	137	69	145	28
AT 540	ET	M	174	129	130	65	124	23
AT 541	ET	M	184	147	142	69	138	26
AT 548	SK	M	193	147	132	76	144	28
AT 727	TUK	M	177	149	132	65	131	25
AT 757	TUK	M	179	159	130	67	155	28
AT 154	ES	F	179	142	117	71	136	24
AT 528	DU	F	178	123	127	68	117	25
AT 566	DU	F	176	139	131	69	132	26
AT 407	DU	M	176	146	137	67	135	29
AT 357	MK (X)	F	166	152	123	54	121	22

Catalog #	NLH	OBH	OBB	BNL	BPL	EKB	ZMB	DKB	MAB	MAL
AT 409	49	33	37	89	82	90	91	17	63	38
AT 537	49	32	39	96	92	95	84	20	59	48
AT 684	48	33	39	92	97	97	91	23	52	41
AT 745	46	34	38	97	96	95	88	23	49	38
AT 907	46	31	36	95	85	91	87	19	48	44
AT 908	45	33	34	88	83	88	87	20	60	37
AT 909	47	40	34	93	79	91	80	22	53	41
AT 033	51	35	39	104	96	100	92	23	62	45
AT 023	58	34	42	100	92	101	96	20	63	50
AT 035	51	31	39	93	96	100	100	20	61	50
AT 036	61	33	42	104	98	104	111	19	63	49
AT 145	69	37	40	103	91	95	102	18	61	51
AT 146	58	33	39	102	101	99	99	23	66	53
AT 164	53	36	39	100	100	99	99	21	61	48
AT 259	51	30	39	92	98	98	92	25	64	48
AT 260	53	39	43	103	91	107	116	25	67	46
AT 292	54	42	36	104	93	106	107	25	64	51
AT 293	53	37	42	93	96	102	102	20	63	46
AT 539	54	32	41	108	99	102	105	21	64	49
AT 540	52	34	39	95	74	88	95	19	61	41
AT 541	50	34	40	109	103	102	96	24	64	51
AT 548	57	36	40	99	89	101	114	21	69	44
AT 727	46	30	40	99	95	96	89	21	54	49
AT 757	55	36	41	97	96	101	102	23	65	49
AT 154	54	36	41	91	83	95	100	19	63	43
AT 528	51	37	38	100	80	91	81	24	59	41
AT 566	51	32	42	97	97	101	95	18	64	48
AT 407	52	37	41	100	93	104	95	24	62	60
AT 357	43	32	34	84	80	88	83	20	62	40

Catalog #	Site	Sex	GOL	XCB	BBH	NPH	ZYB	NLB
AT 361	TA	F	193	151	133	78	141	27
AT 362	KT	F	175	136	124	68	127	23
AT 365	TK	M	182	136	121	67	128	26
AT 367	TK	M	192	150	135	75	140	27
XT M10:1	TJZ	F	177	135	131	65	131	27
XT M10:10	TJZ	F	185	148	131	66	134	28
XT M10:4	TJZ	F	177	135	133	57	118	26
XT M10:5A	TJZ	F	182	128	122	66	126	25
XT M10:9	TJZ	F	178	136	125	71	131	27
XT M11:1	TJZ	F	181	131	130	58	122	24
XT M11:4	TJZ	F	180	131	130	60	130	27
XT M11:6	TJZ	F	174	138	133	63	127	27
XT M12:1	TJZ	F	178	133	123	62	126	27
XT M12:3	TJZ	F	182	148	135	69	133	27
XT M16:2	TJZ	F	184	133	125	63	129	28
XT M16:3	TJZ	F	166	125	119	54	106	22
XT M2:4	TJZ	F	184	136	136	69	137	25
XT M20:5A	TJZ	F	181	136	122	67	133	28
XT M22:1	TJZ	F	180	138	131	65	131	28
XT M22:2	TJZ	F	174	137	131	65	131	27
XT M22:6	TJZ	F	180	133	131	63	124	27
XT M22:7	TJZ	F	176	137	126	68	127	22
XT M24:1	TJZ	F	178	131	127	62	128	28
XT M24:13	TJZ	F	174	137	127	70	131	29
XT M24:3	TJZ	F	176	133	127	71	124	25
XT M24:4	TJZ	F	175	133	128	62	131	26
XT M24:7	TJZ	F	167	133	126	64	123	25
XT M24:9	TJZ	F	178	137	136	66	127	24
XT M25:5	TJZ	F	184	135	125	69	132	31

Catalog #	NLH	OBH	OBB	BNL	BPL	EKB	ZMB	DKB	MAB	MAL
AT 361	60	34	40	104	92	100	99	23	72	65
AT 362	51	37	42	98	98	95	88	19	57	48
AT 365	52	34	36	95	99	90	89	17	64	53
AT 367	59	37	40	102	97	97	104	20	62	45
XT M10:1	52	35	38	100	88	95	90	22	61	44
XT M10:10	50	37	36	94	92	93	103	24	65	46
XT M10:4	46	31	35	100	95	88	82	19	65	47
XT M10:5A	49	33	38	87	83	93	97	19	66	50
XT M10:9	53	33	40	98	96	100	97	22	53	51
XT M11:1	44	32	47	97	101	99	97	22	61	54
XT M11:4	52	33	40	104	94	98	101		64	46
XT M11:6	49	33	39	92	91	98	103	22	67	47
XT M12:1	49	33	35	96	91	92	91	27	62	44
XT M12:3	51	36	40	101	94	97	99	22	71	44
XT M16:2	48	32	38	94	95	99	102	23	66	48
XT M16:3	41	31	34	87	75	84	81	18	58	37
XT M2:4	55	35	39	102	96	94	98	21	68	47
XT M20:5A	50	35	40	96	96	100	97	23	63	47
XT M22:1	54	41	44	99	86	101	102	24	59	42
XT M22:2	52	36	36	100	93	91	100	21	66	44
XT M22:6	50	32	38	103	95	93	99	20	62	49
XT M22:7	49	36	39	94	88	94	93	20	62	45
XT M24:1	49	36	41	95	98	98	89	20	59	33
XT M24:13	54	34	42	95	95	98	98	23	61	50
XT M24:3	54	34	38	95	96	93	93	20	63	48
XT M24:4	51	33	39	99	94	94	96	18	58	47
XT M24:7	47	37	39	90	78	90	87	14	63	43
XT M24:9	50	33	38	101	95	95	100	21	69	50
XT M25:5	53	34	39	99	103	97	97	19	63	55

Catalog #	Site	Sex	GOL	XCB	BBH	NPH	ZYB	NLB
XT M26:2A	TJZ	F	176	133	127	66	128	23
XT M3:6	TJZ	F	179	145	139	72	128	24
XT M34:3	TJZ	F	185	141	131	71	131	23
XT M5:11	TJZ	F	179	134	128	62	127	24
XT M5:4	TJZ	F	187	140	122	71	140	23
XT M52:2	TJZ	F	172	134	129	70	127	27
XT M55:2	TJZ	F	178	136	129	71	128	25
XT M55:3	TJZ	F	165	134	124	66	128	28
XT M55:4	TJZ	F	177	146	135	57	133	29
XT M55:5	TJZ	F	176	129	123	67	127	24
XT M6:4	TJZ	F	184	135	132	71	128	24
XT M6:6	TJZ	F	179	138	135	68	130	30
XT M61:1	TJZ	F	184	139	127	58	125	26
XT M7:1	TJZ	F	180	134	133	75	125	28
XT M7:2	TJZ	F	170	129	128	64	127	27
XT M7:3	TJZ	F	188	139	134	63	134	27
XT M73:2	TJZ	F	183	141	129	63	138	27
XT M77:2	TJZ	F	179	134	140	60	121	25
XT M8:4	TJZ	F	175	142	122	69	141	28
XT M8:5	TJZ	F	183	133	134	61	133	31
XT M8:8	TJZ	F	173	135	126	64	134	25
XT M80:2	TJZ	F	179	130	127	71	128	30
XT M87:1	TJZ	F	176	138	138	66	128	25
XT M9:1	TJZ	F	171	144	128	74	136	25
XT M9:10	TJZ	F	175	128	125	68	130	25
XT M9:4	TJZ	F	177	137	129	68	128	25
XT M9:6	TJZ	F	173	143	137	72	133	28
XT M9:7	TJZ	F	185	144	145	68	134	25
XT M90:2	TJZ	F	166	131	123	67	121	25

Catalog #	NLH	OBH	OBB	BNL	BPL	EKB	ZMB	DKB	MAB	MAL
XT M26:2A	52	34	38	96	89	94	92	20	64	41
XT M3:6	56	36	43	102	93	95	89	21	64	43
XT M34:3	56	37	40	94	75	94	98	16	67	38
XT M5:11	48	35	41	98	102	98	89	21	63	50
XT M5:4	59	41	42	84	91	101	100	19	68	45
XT M52:2	51	33	37	96	48	92	99	20	67	48
XT M55:2	52	34	38	93	92	92	92	18	63	50
XT M55:3	47	35	36	89	86	89	90	19	62	46
XT M55:4	45	34	41	101	97	96	96	19	63	43
XT M55:5	53	34	39	92	95	95	92	18	63	47
XT M6:4	51	33	36	97	96	92	97	22	61	50
XT M6:6	54	35	37	100	96	97	100	23	66	37
XT M61:1	46	33	35	93	87	91	93	21	67	43
XT M7:1	60	39	43	103	97	98	97	19	61	46
XT M7:2	49	35	39	95	92	93	93	17	65	45
XT M7:3	52	35	40	100	95	98	97	19	62	50
XT M73:2	50	32	36	101	100	91	104	24	61	50
XT M77:2	46	31	38	97	95	90	91	17	59	43
XT M8:4	55	39	42	95	92	102	105	19	68	48
XT M8:5	52	36	42	102	80	100	101	22	67	46
XT M8:8	51	38	40	91	87	101	99	22	68	44
XT M80:2	52	35	38	98	94	92	95	21	63	54
XT M87:1	50	36	36	101	90	94	92	25	65	43
XT M9:1	58	38	39	99	86	96	94	20	69	43
XT M9:10	51	37	37	93	90	94	95	21	66	51
XT M9:4	51	35	38	96	95	95	101	25	61	45
XT M9:6	59	37	39	97	94	101	104	25	58	47
XT M9:7	52	35	38	101	93	95	103	21	69	47
XT M90:2	50	37	37	88	84	90	92	16	50	45

Catalog #	Site	Sex	GOL	XCB	BBH	NPH	ZYB	NLB
XT M11:5A	TJZ	I	171	124	123	52	106	21
XT M2:6	TJZ	I	185	139	134	63	131	29
XT M24:11	TJZ	I	184	141	148	69	138	27
XT M26:6	TJZ	I	167	133	122	54	113	25
XT M26:9	TJZ	I	173	136	134	69	132	25
XT M77:1	TJZ	I	180	144	134	72	135	24
XT M9:5	TJZ	I	160	126	117	49	96	18
XT M10:7	TJZ	M	182	132	132	70	134	24
XT M11:2	TJZ	M	192	136	138	66	139	27
XT M12:4	TJZ	M	188	140	136	75	130	27
XT M2:1	TJZ	M	184	140	135	76	135	27
XT M2:9	TJZ	M	187	141	131	59	132	29
XT M20:1	TJZ	M	179	142	130	74	140	21
XT M20:4	TJZ	M	180	137	124	70	117	28
XT M20:6	TJZ	M	185	139	139	76	137	27
XT M22:5	TJZ	M	184	145	141	76	149	27
XT M24:12	TJZ	M	189	136	140	74	136	25
XT M24:2	TJZ	M	185	140	139	66	136	25
XT M24:5	TJZ	M	192	142	145	71	139	26
XT M25:4A	TJZ	M	187	136	135	75	134	25
XT M26:1	TJZ	M	190	142	137	69	145	30
XT M26:5	TJZ	M	178	138	136	71	137	24
XT M26:8	TJZ	M	186	141	143	73	140	26
XT M3:3A	TJZ	M	185	139	136	73	130	28
XT M34:1	TJZ	M	190	146	136	76	138	27
XT M5:14	TJZ	M	189	138	137	71	140	30
XT M52:1	TJZ	M	184	148	142	72	140	27
XT M55:1	TJZ	M	190	146	134	77	146	27
XT M55:6	TJZ	M	187	146	129	78	139	31

Catalog #	NLH	OBH	OBB	BNL	BPL	EKB	ZMB	DKB	MAB	MAL
XT M11:5A	42	33	34	80	70	78	77	15	55	35
XT M2:6	52	32	40	101	95	97	98	23	65	47
XT M24:11	48	36	42	98	93	97	110	20	66	48
XT M26:6	44	34	32	85	77	88	82	24	62	40
XT M26:9	49	33	37	98	98	95	100	25	62	53
XT M77:1	54	37	39	97	92	96	95	23	62	48
XT M9:5	36	30	30	75	69	73	70	16	51	34
XT M10:7	55	35	41	97	91	96	96	22	64	49
XT M11:2	54	36	43	106	97	101	102	23	62	46
XT M12:4	59	36	43	103	94	102	104	23	67	52
XT M2:1	59	36	38	105	99	100	103	24	66	48
XT M2:9	51	34	40	95	85	99	103	19	59	44
XT M20:1	54	35	41	94	88	94	98	19	67	50
XT M20:4	53	37	40	90	88	93	98	21	62	49
XT M20:6	55	36	39	97	94	96	104	22	71	51
XT M22:5	56	38	43	103	91	105	110	21	62	48
XT M24:12	54	35	39	102	89	98	104	23	68	46
XT M24:2	51	34	40	96	81	96	108	19	61	43
XT M24:5	51	37	42	107	97	97	106	17	72	50
XT M25:4A	55	36	38	101	97	97	107	17	65	52
XT M26:1	54	35	41	108	101	102	108	23	68	48
XT M26:5	56	36	40	102	91	97	97	21	59	46
XT M26:8	59	38	45	109	93	101	104	20	63	43
XT M3:3A	58	36	41	104	93	96	98	24	60	42
XT M34:1	57	36	40	100	96	98	98	17	69	53
XT M5:14	54	35	42	104	98	105	104		67	45
XT M52:1	57	33	38	103	93	96	104	23	68	45
XT M55:1	57	39	43	106	101	105	112	25	71	51
XT M55:6	55	37	41	104	101	101	107	23	70	53

Catalog #	Site	Sex	GOL	XCB	BBH	NPH	ZYB	NLB
XT M6:1	TJZ	M	176	135	131	68	131	26
XT M7:4	TJZ	M	193	138	134	67	141	27
XT M7:5	TJZ	M	188	136	140	76	135	29
XT M7:6	TJZ	M	183	141	144	68	142	29
XT M75:1	TJZ	M	178	150	132	66	138	26
XT M8:7	TJZ	M	187	145	132	71	145	26
XT M80:1	TJZ	M	187	138	131	73	144	29
XT M84:2	TJZ	M	182	143	132	72	134	26
XT M9:2	TJZ	M	191	149	140	72	141	30
XT M9:3	TJZ	M	188	134	143	78	133	25
XT M9:8	TJZ	M	185	140	132	78	137	25

Catalog #	NLH	OBH	OBB	BNL	BPL	EKB	ZMB	DKB	MAB	MAL
XT M6:1	54	32	39	98	95	91	95	17	61	42
XT M7:4	54	37	40	103	95	103	100	25	63	48
XT M7:5	60	37	39	105	90	100	101	27	69	46
XT M7:6	57	37	41	109	81	101	96	22	65	40
XT M75:1	52	37	40	99	96	98	95	25	62	47
XT M8:7	52	38	44	102	91	104	105	24	69	46
XT M80:1	56	37	42	103	100	105	106	26	70	51
XT M84:2	53	37	39	96	96	96	99	23	60	52
XT M9:2	58	38	44	108	97	107	103	28	65	48
XT M9:3	59	35	39	103	95	94	103	20	72	48
XT M9:8	60	37	41	100	91	100	99	23	67	47

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Curriculum Vitae

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